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GEOLOGIC HAZARDS IN SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

1976

CALIFORNIA DIVISION OF MINES AND GEOLOGY

Prepared in cooperation with the County of San Bernardino Environmental Improvement Agency, the County of San Bernardino Planning Department, and the U. S. Geological Survey.

SPECIAL REPORT 113

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Special Report 113

GEOLOGIC HAZARDS IN SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

by
Donald L. Fife
and
Donald A. Rodgers, Gordon W. Chase, Rodger H. Chapman, and Edward C. Sprotte

GEOLOGIC, FAULT, AND MAJOR LANDSLIDE AND SLOPE STABILITY MAPS
by
Douglas M. Morton
U.S. Geological Survey

1976

California Division of Mines and Geology
1416 Ninth Street, Room 1341
Sacramento CA 95814

Prepared in cooperation with the County of San Bernardino Environmental Improvement Agency, the County of San Bernardino Planning Department, and the U.S. Geological Survey.

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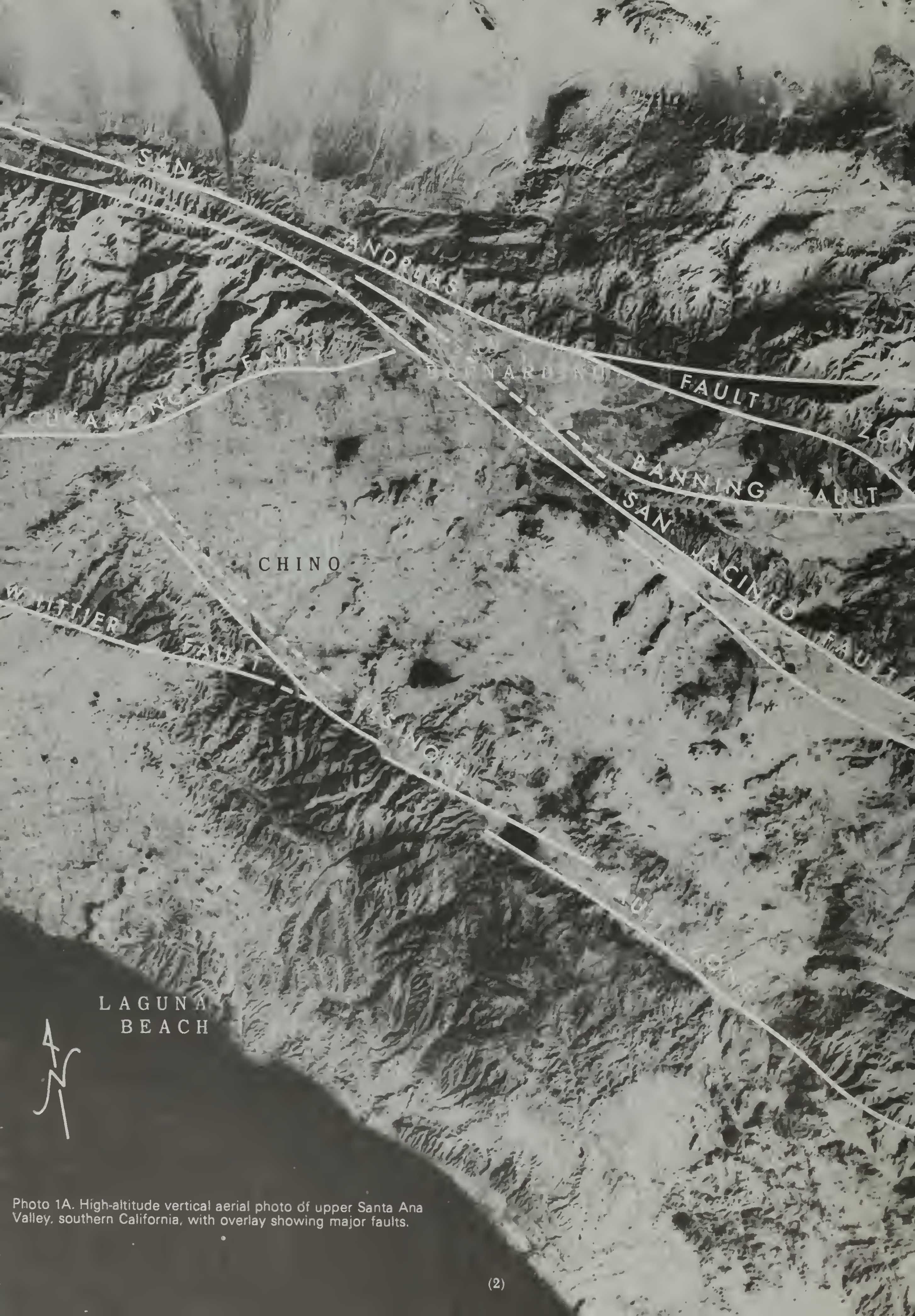
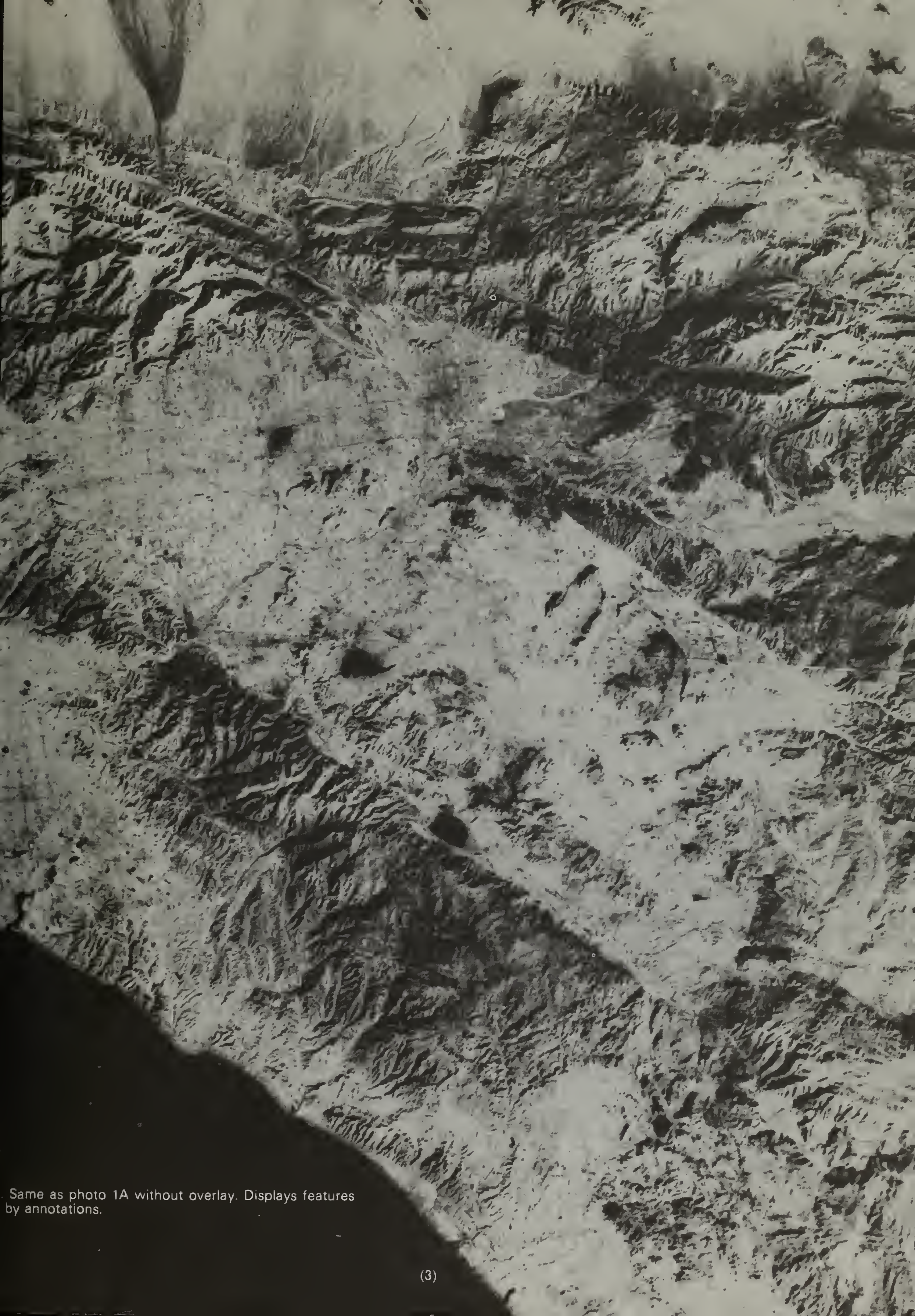


Photo 1A. High-altitude vertical aerial photo of upper Santa Ana Valley, southern California, with overlay showing major faults.



Same as photo 1A without overlay. Displays features
by annotations.

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ABSTRACT

The study area encompasses 550 square miles (1400 km^2) of the Upper Santa Ana Valley in southwestern San Bernardino County and has a population of 600,000. The active Cucamonga, San Jacinto, San Andreas, and Elsinore faults are within the region. Based on well data and magnetic measurements, a principal trace of the Elsinore fault is believed to extend northwesterly, east of the Puente Hills. The San Jacinto fault, which was not considered during early land development, presents the greatest hazard from ground rupture in the urbanized San Bernardino area. The San Andreas fault, until this year (1974), has been similarly disregarded.

Ground shaking, resulting from fault movement, is a serious seismic hazard in areas of widespread alluvial sediments. The thickness of alluvial sediments averages about 800 feet (240 m) in the valley area with maximum thicknesses of about 1300 feet (396 m) near Ontario and San Bernardino. The surface effects of shaking will probably be greatest in areas of ground-water depletion and subsidence near San Bernardino and Chino.

Depletion of ground water and draining of swamps during the first half of this century have largely eliminated the liquefaction hazard; however, urban irrigation maintains perched water tables, which may present local liquefaction hazards.

The region experienced major seismic events in 1769, 1812, and 1857; and five strong earthquakes near magnitude 6 or greater were experienced in the region between 1890 and 1923. Landslide-prone areas within the National Forest along the mountain front of the Transverse Ranges present hazards to dams, reservoirs, roads, railroads, and utilities. The Puente Hills, which are underlain by Tertiary marine sedimentary rocks, are considered the most hazardous landslide-prone area.

Geologic Hazards in Southwestern San Bernardino County, California

By Donald L. Fife[1], Donald A. Rodgers[2], Gordon W. Chase[3], Rodger H. Chapman[3], and Edward C. Sprotte[4]

SUMMARY OF FINDINGS

Ground Rupture and Ground Shaking

Southwestern San Bernardino County has been subjected to damaging earthquakes in the past, and in the future damage may result from earthquakes centered on faults within the study area or from earthquakes originating outside the area. Surface rupture may be devastating to structures located on a fault. Most structures will not be located directly on a fault and will sustain damage due to the effects of ground shaking or landsliding.

At least four major active or potentially active fault zones are found within the study area: the San Jacinto, the Chino-Corona segment of the Elsinore, the Cucamonga, and the San Andreas. Numerous minor faults associated with these may also represent significant hazards.

During the 33 years from 1890 to 1923, the local San Bernardino region experienced five significant earthquakes with estimated local magnitudes of 6 or greater. Each one of these earthquakes resulted in energy release roughly equivalent to the energy released in the 1971 San Fernando earthquake, which caused 64 deaths and cost $550 million in damage (Kachadoorian, 1971). Historically, the San Jacinto fault zone, which passes through Rialto, San Bernardino, and Colton and continues south into the San Jacinto Valley in Riverside County, is the most active fault zone in southern California. The most recent earthquakes on this fault have been centered in Riverside and San Diego Counties. Geologic evidence indicates the San Jacinto fault has been active for millions of years and recent surveys indicate the fault is undergoing minor creep in the Colton area. It has been 52 years since a significant earthquake occurred in the San Bernardino region, and it appears that a moderate to large earthquake may be overdue somewhere along the northern segment of the San Jacinto fault zone.

The Chino-Corona segment of the Elsinore fault zone is the least known of the major fault zones affecting the study area. As referred to in this report, the Chino-Corona segment of the Elsinore fault zone is defined as that portion of the northwest-trending Elsinore fault zone that includes the Chino fault (Gray, 1961), the Central Avenue fault (Woodford and others, 1944), and newly inferred unnamed subsurface fault(s) that separate the Puente Hills from the Perris Block between Bedford Wash on the south and the San Jose Hills on the north. The trend of this segment is similar to the "Elsinore Fracture Zone" of Barbat (1958). Because of the Holocene alluvial deposition and agricultural usage, surface or near-surface evidence of fault rupture along this fault zone may have been obliterated. Further investigation is needed to define this potential geologic hazard. There is evidence of faulting in deeper, stratigraphically older sediments and the underlying crystalline rocks. Fault displacement of Quaternary (Jennings, 1973) and Holocene age (Ziony and others, 1974) is attributed to the Central Avenue fault, and fault displacement of Quaternary and late Quaternary age is attributed to the Chino fault.

To the south in Riverside County, geologically young features and historic seismic activity imply that the Elsinore fault zone is active; movement of faults in this zone range from right-lateral sense of movement to a reverse, or possibly thrust, sense of movement (Weber, 1974).

The current work strongly suggests that a principal northern extension of the Elsinore fault zone trends northwestly into the study area and includes the Chino, the Central Avenue fault, and the unnamed subsurface fault(s) mentioned above. The Whittier fault on the west, outside the study area, may represent a branch or segment of the Elsinore fault zone but is possibly not the main projection of the Elsinore fault. Resolution of this possibility will require additional surface and subsurface investigation.

The Cucamonga fault zone, part of the southern Transverse Range fault system of left-lateral reverse faults, represents an eastern end of this zone. The Cucamonga fault zone is considered to be active, based on its relatively young geologic expression and on seismic evidence, particularly the 1971 San Fernando earthquake which took place within the southern Transverse Range fault system. Earthquakes comparable to the 1971 San Fernando earthquake should be expected along the Cucamonga fault. Some geologists believe the Banning fault represents an offset segment of the Cucamonga fault which has been displaced about

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[1] Geologist.
[2] Seismologist.
[3] Geophysicist.
[4] Petroleum Geologist.

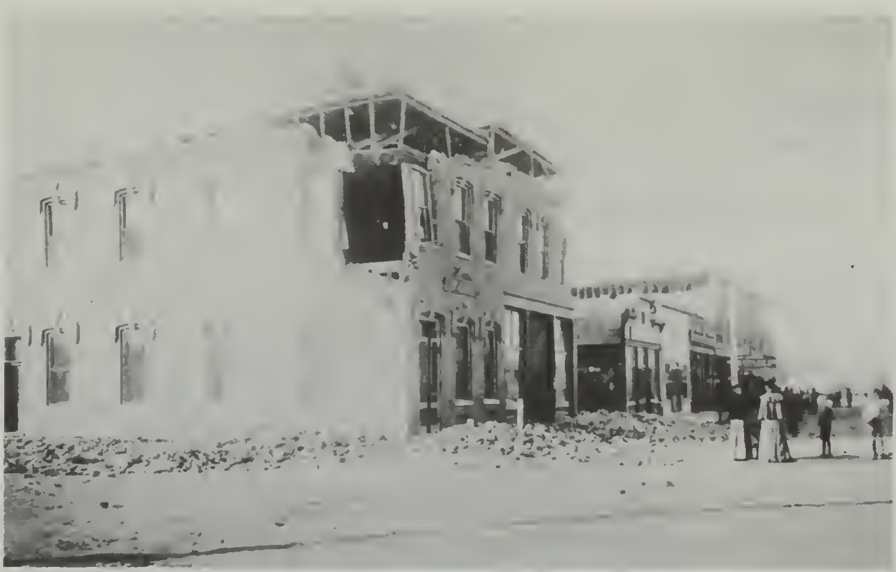


Photo 2. Earthquake damage on Main Street, San Jacinto, California, resulting from the December 1899 earthquake on the San Jacinto fault. Loose bricks and falling debris are common hazards during an earthquake. Photo courtesy of Charles Van Fleet.

Photo 3. Seismically induced landslide in Bautista Canyon resulting from the December 1899 earthquake on the San Jacinto fault. Note the three men are standing between the scarp and a fresh crack on an unstable block. Photo courtesy of Charles Van Fleet.

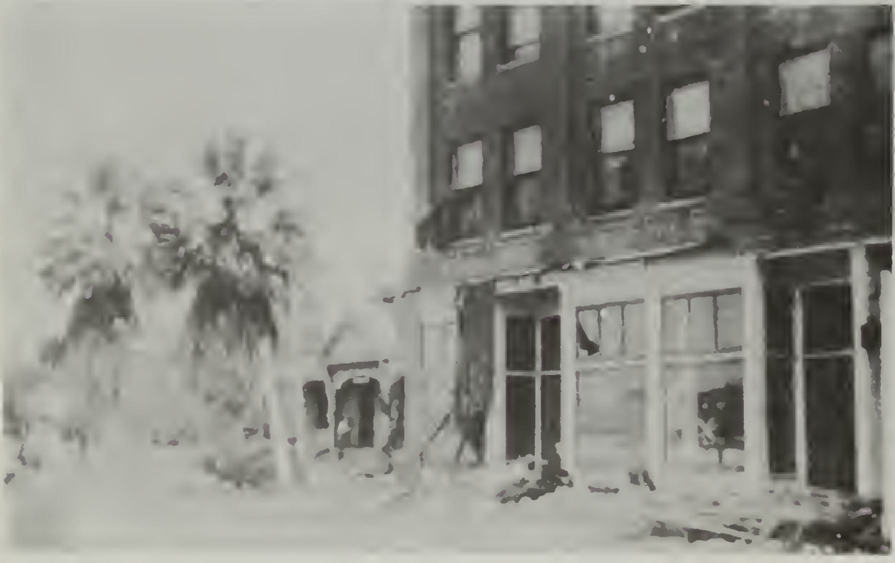


Photo 4. Earthquake damage in San Jacinto, California, resulting from the April 1918 earthquake on the San Jacinto fault, only 19 years after the 1899 earthquake. Note the loose debris on the sidewalk. This type of nonstructural decorative facing is severely restricted by modern building codes. Photo courtesy of A. V. Doyle.

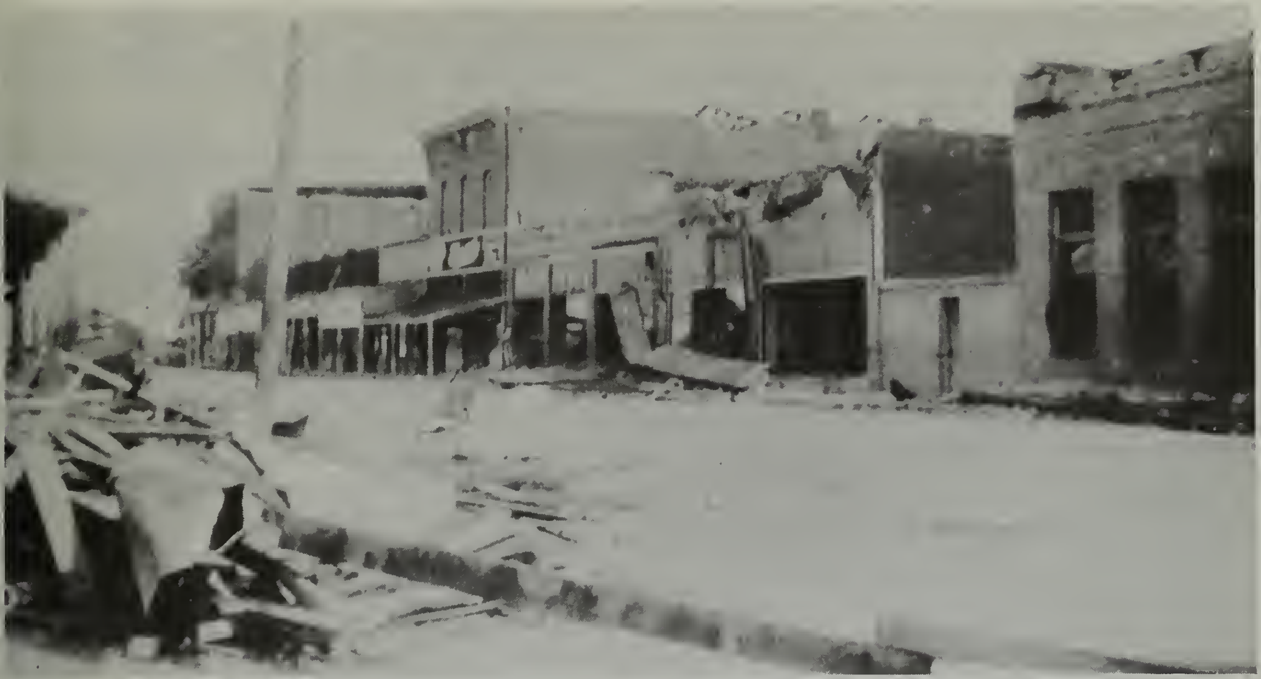


Photo 5. Another view of earthquake damage in San Jacinto resulting from the April 1918 earthquake. Much of the decorative masonry work, as well as shades and signboards, collapsed onto the sidewalk during the earthquake. Photo courtesy of A. V. Doyle.

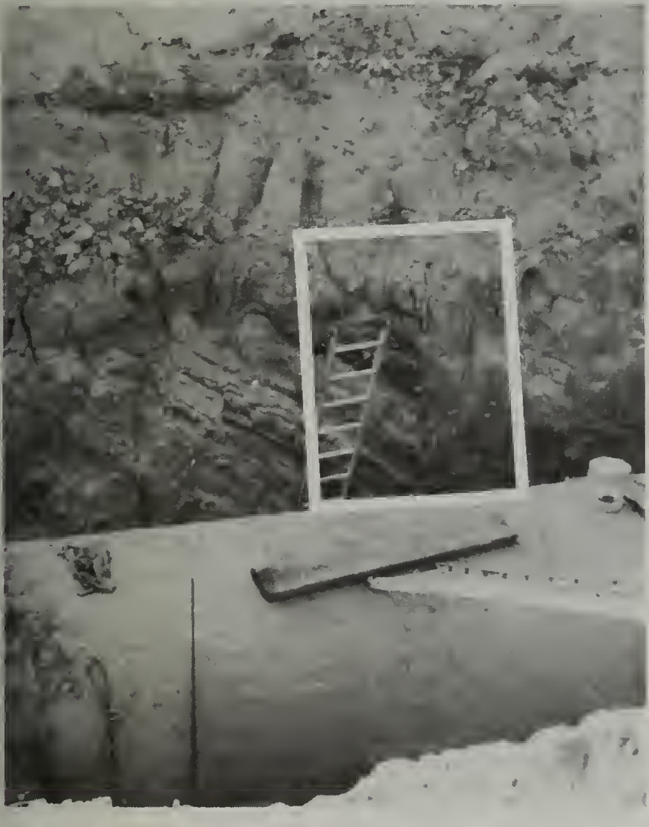


Photo 6. Breaks in the Holocene alluvium overlying the San Jacinto fault in the California Aqueduct pipeline trench about 700 feet (210 m) north of Foothill Boulevard in west San Bernardino. The 9-foot (2.75-m) diameter highpressure pipeline was placed next to the Lytle Creek flood control channel through this part of the city. White rectangle enlarged in photo 7. Photo by Donald L. Fife, 1971.

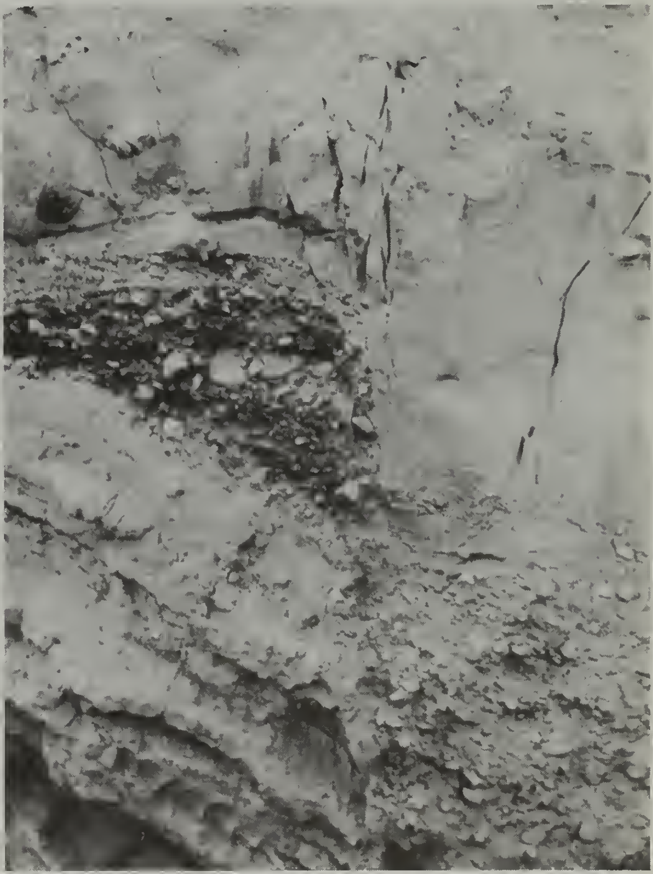


Photo 7. Close-up of Holocene San Jacinto fault break shown in photo 6. Observer is looking down the strike of this lateral fault break. Several similar breaks transect the pipeline trench at this locality. Photo by Donald L. Fife, 1971.

18-25 miles (30-40 km) southeast along the San Jacinto fault (Baird and others, 1974).

In 1857 a magnitude 8+ (estimated) earthquake occurred on the San Andreas fault, and the ground was ruptured for 200 to 275 miles (320 to 440 km) from near Cholame to Cajon Pass and possibly as far south as the San Gorgonio Pass (Wood, 1955). Wallace (1968) estimated the recurrence interval for a magnitude 8 earthquake along the total length of the fault to be between 50 and 200 years. It has been 117 years since the rupture in 1857. Most geologists and seismologists believe stress is building up on the San Andreas fault because of the resistance created by the curvature of the fault in southern California and will eventually be released in an earthquake similar to the 1857 event. Such an earthquake would have a significant impact on the 700,000 residents of San Bernardino County, as well as the several millions in adjacent counties.

A magnitude 7.5 earthquake on the San Jacinto fault would subject most of the San Bernardino area to ground acceleration over 0.5 g with higher accelerations in the mountains. Maximum peak bedrock acceleration from a magnitude 7.5 earthquake on the Elsinore-Whittier fault would range from about 0.7 g on the southwest county line to 0.4 g near Ontario. The maximum peak bedrock accelerations from a magnitude 6.5 earthquake on the Cucamonga fault would be over 0.5 g but generally confined to the area within about 6 miles (10 km) of the fault trace. Maximum peak bedrock accelerations well over 0.5 g would be generated throughout most of the San Bernardino area by a magnitude 8+ earthquake on the San Andreas fault.

Landslides and Slope Stability

The steep mountain slopes of the San Gabriel and San Bernardino Mountains and the gentle slopes of the Puente Hills are potentially hazardous areas. The San Gabriel and San Bernardino Mountains lie within the National Forest; thus, potential landsliding here will presumably not affect major urban development directly, but will be a hazard to dams, reservoirs, roads, railroads, and utilities.

The 40-square-mile (100 km^2) area of the Puente Hills underlain by marine sedimentary rocks is the most potentially hazardous landslide-prone terrain in southwest San Bernardino County. Probably the greatest hazard results from failure to recognize existing landslides and areas of potential landsliding prior to urban development. If the potentially hazardous areas are recognized in the planning stage, they can often be safely developed, avoided, or removed.

Subsidence and Uplift

Subsidence from ground-water withdrawal is actively progressing within the study area, although the magnitude and significance of subsidence is not completely known.

Subsidence in the Bunker Hill-San Timoteo hydrologic basin appears to be satisfactorily regulated by recharging the basin with imported water. Maximum documented subsidence to date is on the order of 1 foot (30 cm) near Loma Linda.

The extent of subsidence is not completely known. The entire region underlain by the Chino artesian aquifer may be subsiding significantly due to groundwater depletion. The production of petroleum within the county is not presently great enough to cause petroleum related subsidence.

The amount of tectonic subsidence or uplift, if any, is unknown in the valley portion of the study area.

Liquefaction Potential

The potential for liquefaction exists in all the alluviated areas of the study area, with the greatest potential where shallow perched water tables exist. Soils are generally sandy and silty and, when saturated, they have a high potential for liquefaction. Areas of highest potential for shallow ground water less than 50 feet (15 m) generally correspond to the old lowlands or drainage areas of surface waters and swamps of the late 1800s (plates 4A and 4B).

Mineral Resources

Southwest San Bernardino County has extensive sand and gravel resources, located mainly in the large alluvial fans along the base of the San Gabriel and San Bernardino Mountains. Large undeveloped tracts of land exist on these fans, which are underlain by potentially valuable aggregate and by potentially hazardous faults, such as the Cucamonga, San Andreas, and San Jacinto.

With increasing population there is an increasing demand for mineral resources. Effective land use planning must be exercised so valuable resources are not made inaccessible by urbanization.

Geophysical Surveys

Seismic, magnetic, and gravity methods were used to detect fault extensions and to confirm locations of suspected faults in Prado flood control basin, Waterman Creek, Lytle Creek, Cajon Creek, and Santa Ana River washes. The use of seismic refraction data was successful in detecting evidence of faulting along the Glen Helen-Loma Linda fault trend on at least three traverses and possibly three others. Portable seismic equipment and high-energy sources (explosives) are required to obtain more satisfactory seismic results in the poorly consolidated alluvium, artificial fill, and old landfills. Magnetic anomalies, mostly small in amplitude, mark some of the fault traces or projected traces of the Glen Helen, Loma Linda, San Jacinto, and Central Avenue faults. An analysis of the gravity field in the region, however, shows that only very crude estimates of the thickness of the valley fill can be made from the gravity data.

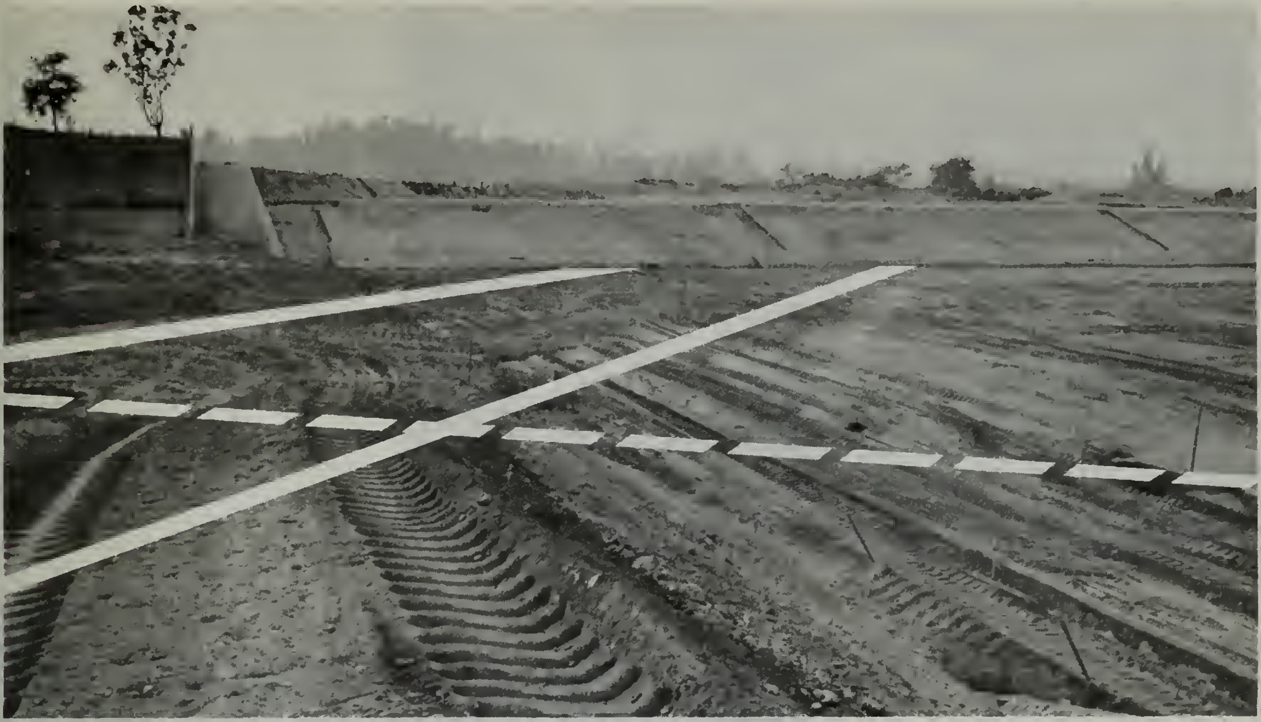


Photo 8. Lytle Creek flood control dam (center back) and buried California Aqueduct pipeline (dashed line) cross a branch of the San Jacinto fault zone (solid white lines) north of Foothill Boulevard in west San Bernardino; view west. The fault zone trends northwest. The disturbed zone within the Holocene alluvium (between the solid white lines) is more than 50 feet (15 m) wide. The buried pipeline (Note manhole cover at far left center) is shown in photo 6 before fill was placed around it. The California Aqueduct has about 700 feet (210 m) of head at this location. Photo by Donald L. Fife, 1975.

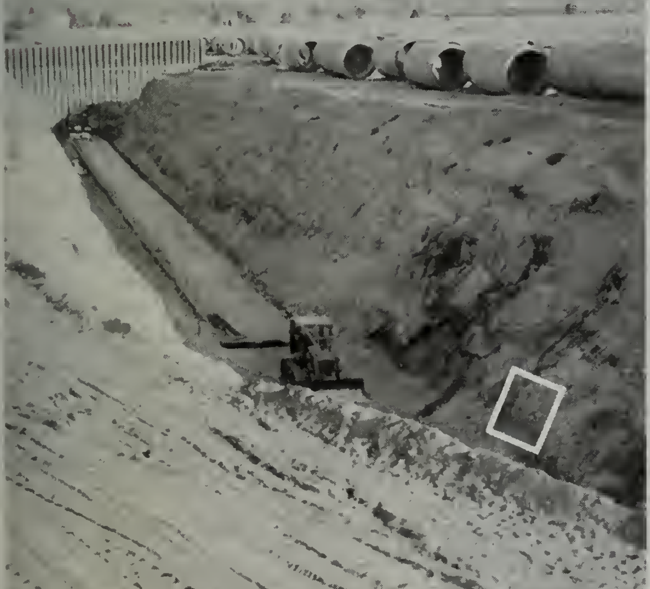


Photo 9. San Jacinto fault capped by 38 feet (11.5 m) of "modern" (1969) alluvium in the California Aqueduct pipeline trench in Lytle Creek flood control channel at Warm Creek in southwest San Bernardino. White rectangle enlarged in photo 10. Photo by Donald L. Fife, 1971.

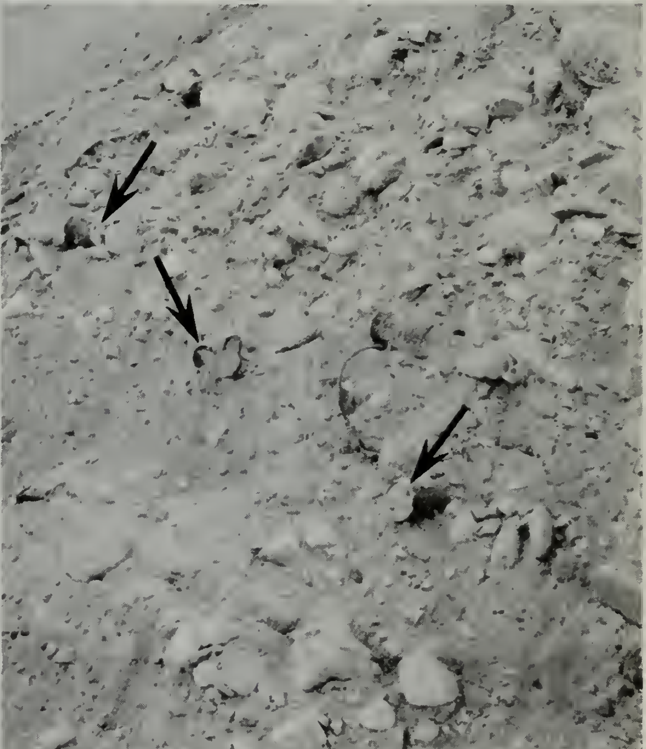


Photo 10. Close-up of "modern" alluvium containing aluminum-top cans as much as 30 feet (9 m) below the ground surface (see photo 9). Thirty-eight feet (11.5 m) of undisturbed, unfaulted "modern" alluvium overlies the active San Jacinto fault zone at this locality. Photo by Donald L. Fife, 1971.

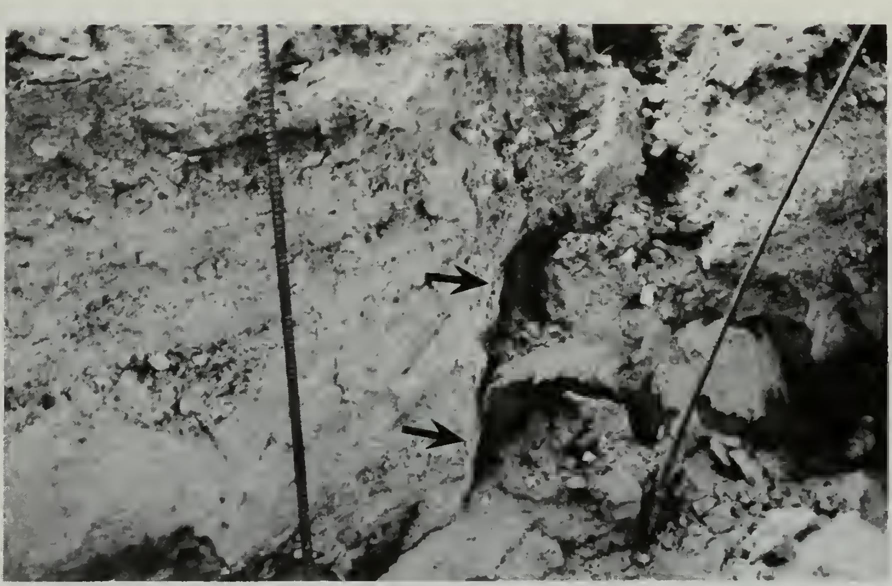


Photo 11. San Jacinto fault exposed in Holocene alluvium in foundation trench near Mill Street in west San Bernardino. The break apparently reached the surface. This site is now (1975) covered by part of a large modern building. New laws (1974) have been enacted to prevent building on active faults. Photo courtesy of Converse-Davis & Associates, Pasadena.

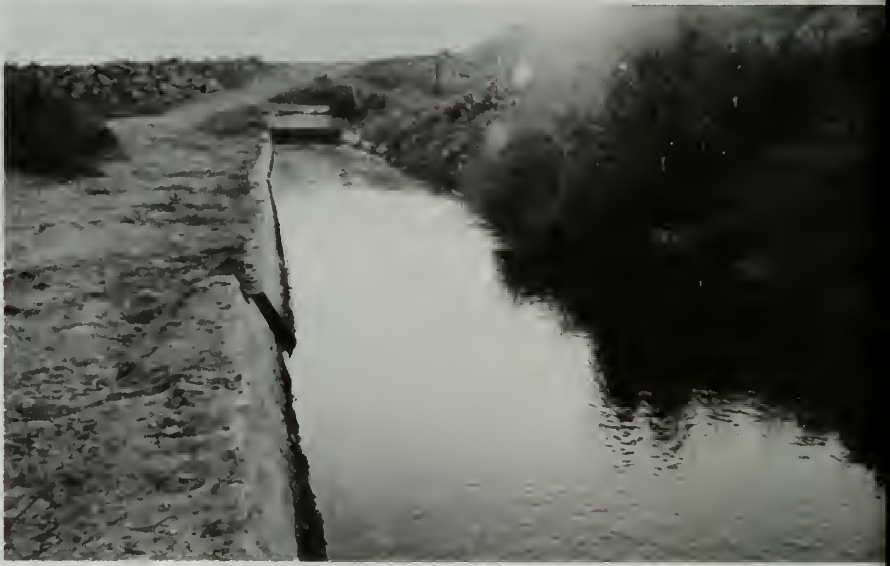


Photo 12. Old canal (circa 1900) showing possible creep and/or expansive soil effects at San Jacinto fault crossing of Warm Creek. Several millimeters of right-lateral creep have been observed on survey figure COLT in this area. The canal lies normal to the fault trace. Apparent right-lateral creep shown in photo is difficult to prove because the canal lining is a patchwork of repairs. Photo by Donald L. Fife, 1974.

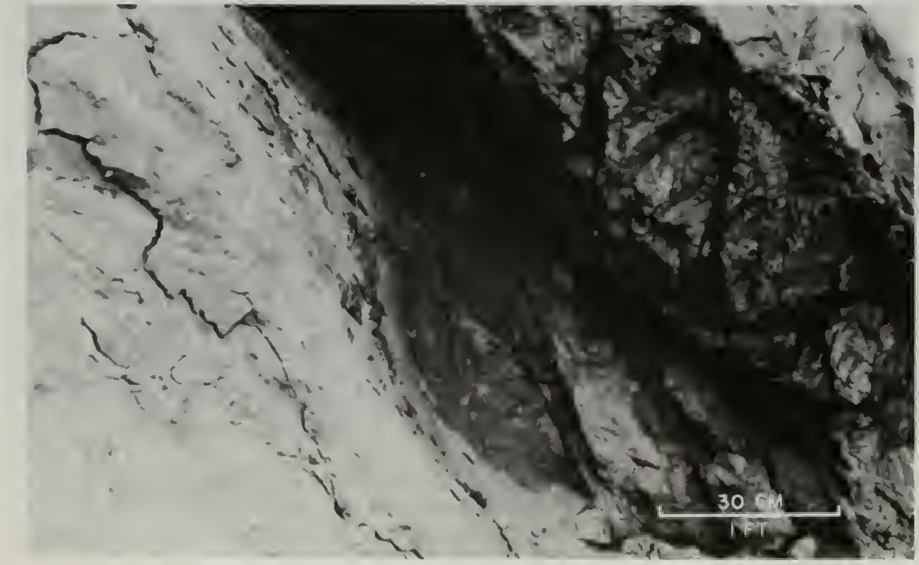


Photo 13. Deformed and altered sedimentary rock and plastic fault gouge from the south end of Bunker Hill Dike (San Jacinto fault zone). Cracking is the result of drying. This expansive material underlies the areas shown in photos, 9, 10, and 11. Photo by Donald L. Fife, 1971.

RECOMMENDATIONS

Active Faults and Ground Rupture

Under provisions of the Alquist-Priolo Geologic Hazard Zones Act (Chapter 7.5, Division 2 of the Public Resources Code), special studies zones have been or are being considered for delineation along active traces of the Cucamonga, San Jacinto, Glen Helen, Loma Linda, and San Andreas faults within the study area. Unidentified active faults also may exist outside of these special study zones with surface traces obscured by natural or human activities.

The generalized fault map (plates 2A and 2B) delineates the traces of known active and potentially active faults. Because of the scale of this map and the limitations of existing geologic knowledge of the area, only the approximate locations of known fault ruptures are shown. All active and potentially active fault traces should be delineated accurately prior to urban development. Structures for human occupancy should not straddle the trace of an active or potentially active fault. Where utilities or pipelines cross an active or potentially active fault, provisions should be made to reduce the hazard.

Landslides and Slope Stability

Since much of the hillside terrain is underlain by potentially unstable material, a detailed soil and geologic slope stability evaluation should be made of specific sites prior to urban development in hillside areas. These investigations should identify and delineate existing landslides, as well as the effects on slope stability of altering the vegetation, the water table, the natural drainage, and the natural slope. Design and engineering work necessary to prevent or correct problems should be set forth in detail prior to construction.

Subsidence

Because the extent of subsidence in the area of this study is not fully known, a program of monitoring first-order level surveys across areas of potential subsidence should be considered. The northern portion of the area, which is now being rapidly urbanized, should be investigated first. A first-order level survey net in the county could be tied into the existing net (Lofgren, 1971) and used to monitor fault movement as well as subsidence. If significant subsidence related to ground-water withdrawal is identified, a program of ground-water management should be implemented.

Liquefaction Potential

Areas of former shallow ground water, swamps, and other surface waters (plates 4A, 4B) should be considered suspect for potential liquefaction. Because many irregular and discontinuous perched water tables exist in the urban areas and because these areas are generally underlain by sandy and silty soils, each site should be evaluated for liquefaction potential prior to design or construction. The site evaluation should include information on soil type, history of water-table fluctuation, and potential for saturation within the upper 50 feet (15 m) of alluvial materials.

Mineral Resources

It is recommended that undeveloped areas underlain by hazardous fault zones and potentially valuable sand and gravel be considered for addition to existing resource zones to keep these resources accessible to the community, as well as to diminish high-density human occupation in an active fault zone. Consideration should be given to coordinating mining with improved flood control, water spreading, recreation, and other compatible land uses. The Alquist-Priolo special studies zone maps should offer a general guide to resource zoning in these geologically hazardous areas.

Discussion of Additional Studies

It is recommended that the following additional studies be considered:

(1) Identify and monitor active and potentially active faults and subsidence areas.
(2) Make detailed gravity, magnetic, seismic, and subsurface geologic studies of the poorly defined fault zones within the study area.
(3) Map the geologic detail of exposed traces of active faults and landslide-prone areas at a scale of 1:12,000 or larger.
(4) Make a study of ground-water barriers paralleling the main trace of the San Andreas fault, including the area 1 mile (1.6 km) southwest of it.

Additional work should be considered for the identification and monitoring of active and potentially active faults. Detailed gravity, magnetic, seismic, and subsurface geologic studies should be considered for the poorly known fault zones within the valley areas. It would also be desirable to have detailed regional geologic mapping at a scale of 1:12,000 or larger along the exposed traces of the active faults as well as in landslide prone areas.

Additional seismic refraction traverses should be made along the little known, but urbanized, segments of the Glen Helen-Loma Linda fault trend in Rialto, San Bernardino, and Loma Linda. The newly inferred extension of the Banning(?) fault projecting northwestward from the mouth of San Timoteo Canyon should be more clearly identified, possibly by trenching, as the fault appears at the ground surface in 1928 aerial photographs.

The ground-water barriers paralleling the main trace of the San Andreas fault about 1 mile (1.6 km) to the southwest should be included in any study of the San Andreas fault. These barriers are probably related to faults, and they underlie heavily urbanized San Bernardino, Patton, and Highland.

It would also be desirable to identify more clearly the faults within the Chino-Corona segment of the

Elsinore fault zone. This might be accomplished with a program of detailed magnetic and seismic refraction surveys and detailed surface and subsurface geologic mapping.

At least two detailed gravity, magnetic, and seismic traverses running northeast across the study area would aid in identifying other presently unknown faults. A northwest traverse normal to the microseismic trend in Fontana would also be useful in identifying the source of seismic activity in that area.

All potentially active faults in the area should be monitored. Microearthquake surveys (Hadley, 1973) should be conducted to identify current seismic activity, as this may be a clue to future seismic events. Small survey figures such as those at COLT, RIALTO, and DEVIL should be established across the faults, using first-order survey techniques, with at least two figures across each fault. If the figures are resurveyed annually, slow movement on the fault could be monitored. In addition, first-order level surveys should connect each survey figure to detect vertical movement. Significant creep or tilt might forewarn of impending earthquakes. To be sure that no faults were missed, first-order trilateration arcs and level lines should be established where lines do not presently exist—possibly along freeways, flood control channels, railroads, or utility corridors. These should be reobserved every 1 to 2 years. Level lines would also be useful in determining and monitoring subsidence.

Many faults are known within the study area, and we can reasonably expect earthquakes and ground rupture on some of them in the future. However, one should not be complacent about the probable existence of unknown faults, as two of the most damaging earthquakes in recent years, the 1952 magnitude 7.7 Arvin-Tehachapi and the 1971 magnitude 6.4 San Fernando earthquakes, occurred on little-known faults or "ground-water barriers."

INTRODUCTION

Purpose

The primary purpose of this report is to review and analyze the available geologic, geophysical, and seismic data in the Upper Santa Ana Valley region of southwestern San Bernardino County (figure 1). Actual and potential geologic hazards are identified and delineated so policies, programs, and ordinances to mitigate these hazards can be developed, and included in the Seismic Safety and Public Safety Elements of the County's General Plan as mandated by California Government Code Sections 65302 and 65302.2. The generalized maps and other data presented in this report are principally intended for general use of geologists, engineers, planners, and other professionals and should not be considered as a substitute for individual site investigations.

Location and Extent of Area

San Bernardino County encompasses 20,160 square miles (52,210 km²) in southeastern California. In areal extent this is the largest political subdivision of its kind in the conterminous United States. Included within the county are portions of four geomorphic provinces—Basin and Range, Mojave Desert, Transverse Ranges, and Peninsular Ranges—bounded in part and dissected by major active and potentially active fault zones—the Cucamonga, Elsinore, San Jacinto, and San Andreas. The study area of this investigation encompasses about 550 square miles (1,420 km²) located in the southwestern portion of the county and includes portions of the south- and southwest-facing areas of the eastern San Gabriel Mountains and San Bernardino Mountains of the Transverse Range Province, and the San Bernardino - Chino Valley - eastern Puente Hills area of the Peninsular Range Province (figure 2). The valley portion of the study area is collectively known as the Upper Santa Ana Valley.

Elevations range from 11,502 feet (3399 m) at Mt. San Gorgonio on the east to 490 feet (150 m) above sea level at the Prado Flood Control Basin in the southwest corner of the area. Most of the Upper Santa Ana Valley is of low relief, with alluvial plains averaging from 1,000 to 1,500 feet (300-460 m) in elevation.

In 1973 the estimated total county population was 700,000. The majority of residents (about 600,000) are located within the study area and concentrated in the cities of Ontario, Upland, Chino, Fontana, Redlands, Rialto, Colton, and San Bernardino. San Bernardino, the County seat, is the largest city, with a population of 110,000.

Climate

The area has a semiarid climate that is much less severe than the Mojave and Colorado desert regime to the north and east. The mean temperature in the San Bernardino area is about 62° F (16.7° C). Extremes range from a maximum of 116° F (46.7° C) to a minimum of 18° F (-7.7° C). Winter temperatures in the valley are sufficiently mild to allow extensive citrus growing. Precipitation ranges from 20 to 40 inches (500 to 1000 mm) annually in the high mountains to approximately 17 inches (430 mm) annually on the central valley floor. Most of the precipitation occurs between October and May.

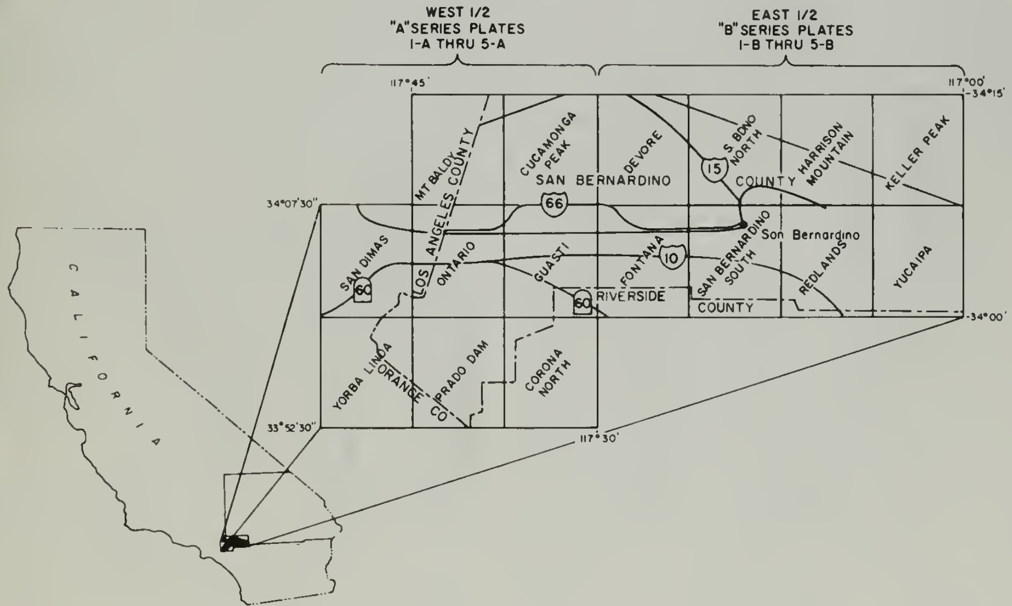


Figure 1. Index map of southwestern San Bernardino County showing study area and U.S. Geological Survey 7.5-minute quadrangles.

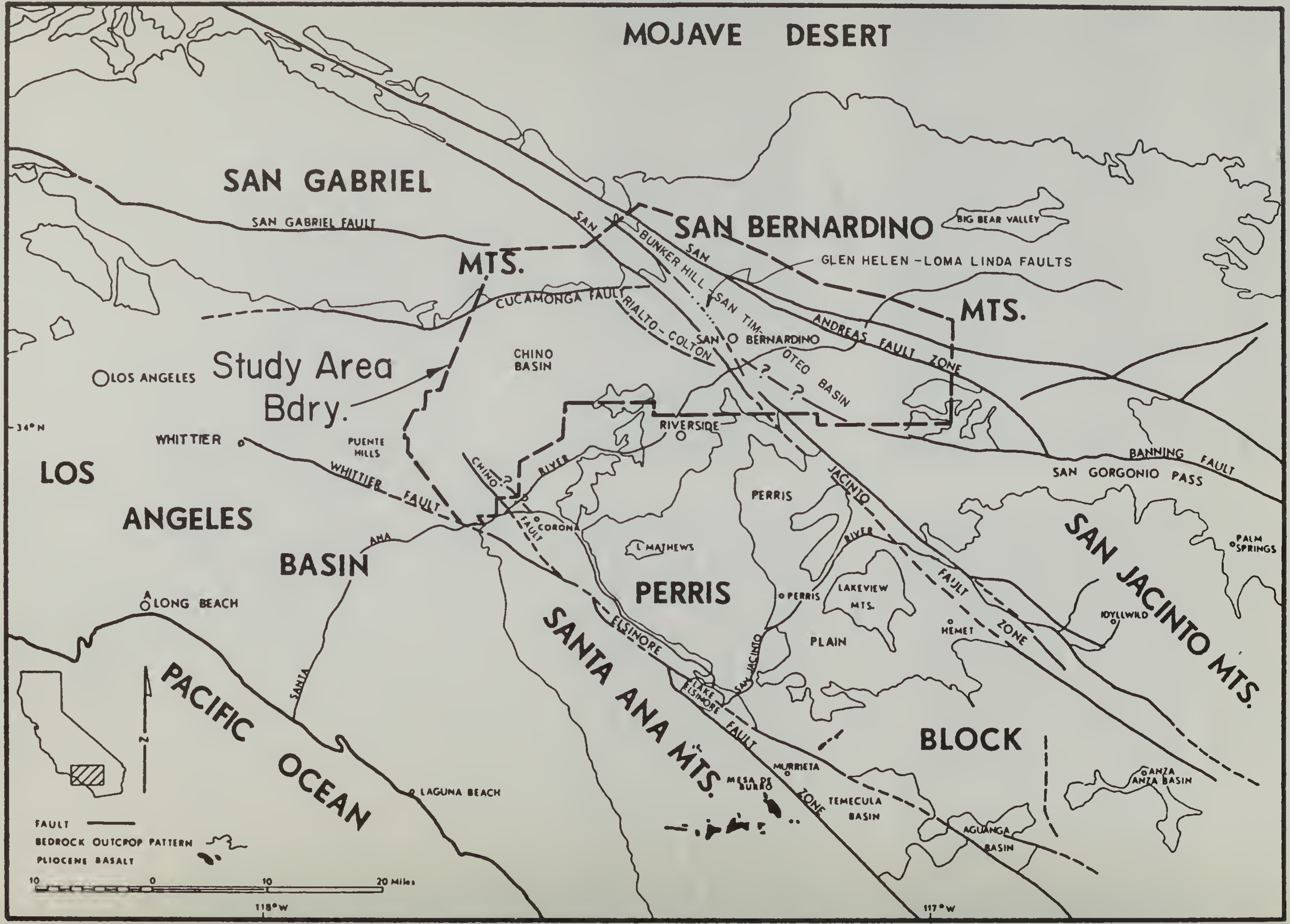


Figure 2. Index map of Upper Santa Ana Valley showing faults, main drainage, geomorphic features, and hydrologic basins. Modified from Woodford and others, 1971.

Drainage and Water Supply

All major drainages flow south and west out of the Transverse Ranges upon actively building alluvial fans into the Santa Ana River, which flows southwestward into the Prado Flood Control Basin. The Santa Ana River then passes through an antecedent course between the northern Santa Ana Mountains and eastern Puente Hills to the Pacific Ocean 25 miles (40 km) west of the study area. The narrows at Prado Dam allow precise measurement of all surface and ground-water flow leaving the Upper Santa Ana Valley. The greatest flood on record was the January 1862 flood, with an estimated outflow from the Prado narrows of 320,000 cfs (9,260 cms) (Sidler, 1973). By comparison, the disastrous flood of March 1938 had an estimated outflow of 100,000 cfs (2,830 cms) from Prado narrows. Prado Dam built in 1941 protects Orange County and a small portion of Riverside and San Bernardino Counties and was constructed to control floods approximating the 1938 flood.

A drought occurred during the late 1800s, and by the early 1900s extensive withdrawal of ground water had caused a serious overdraft on the two principal areas of artesian flow near Chino and around San Bernardino (figure 3). Water has been imported from the Colorado River since the early 1940s and from the California Aqueduct since 1972 to supplement local supply.

Previous Work

Hall (1888) and his assistant, Schuyler, produced the first significant technical information on the area covered by this study. Their maps show surface waters, swamps, and irrigated lands and are the principal source of information concerning early surface- and ground-water conditions. Mendenhall (1905, 1908) made the first significant geologic analysis of the region. Eckis (1934) first summarized the geohydrology of the entire study area. Geologic and hydrologic conditions in the Chino Basin area of the western portion of the study area were covered by Garrett and Thomasson (1949). Dutcher and Garrett (1963) summarized several years of U.S. Geological Survey ground-water related research in the eastern half of the study area and presented the first published detailed analysis of ground water, ground-water barriers, and faulting. The geology of the marine sedimentary rocks of the eastern Puente Hills was studied by Durham and Yerkes (1964). The work of Phillips (1971a, 1971b) was used extensively in compiling information pertaining to areas covered by alluvium within the study area.

The general aspects of the Peninsular Ranges and the Transverse Ranges Provinces are summarized by Jahns (1954a, 1954b) and by Bailey and Jahns (1954). The report of the State Earthquake Investigation Commission (Lawson and others, 1908) contains an account of a reconnaissance of the San Andreas and San Jacinto fault zones made by H.W. Fairbanks after the 1906 San Francisco earthquake.

The most significant historic seismic event to affect the San Bernardino area, the Fort Tejon earthquake of 1857, was reviewed by Wood (1955). This earthquake is judged to have been of about the same or greater intensity as the 1906 San Francisco earthquake (estimated magnitude > 8) and is reported to have created a long "fissure" in south San Bernardino (Wood, 1955).

Crowell (1962) discussed the San Andreas system and proposed lateral offsets of 160 miles (250 km) or more along the fault. Recently Baird and others (1974) discussed some of the problems concerning the continuity of the Transverse Ranges and large lateral offset proposed for the San Andreas fault system.

California Division of Mines and Geology Bulletin 196 (Oakeshott, 1975) reviews the geology, geophysics, and seismology of the 1971 San Fernando earthquake, centered on the western portion of the southern Transverse Range fault system, which extends into southwestern San Bernardino County.

Sharp (1967) reviewed the San Jacinto fault, mainly considering its effects south of San Bernardino County. Because this fault is one of the most active in California, its movement and history, even outside the area of study, are important. U.S. Geological Survey Professional Paper 787 reviews the 1968 Borrego Mountain earthquake on the San Jacinto fault and the synchronous movement on neighboring faults during this event. California Division of Mines and Geology Preliminary Report 13 (Jennings, 1973) summarizes the current knowledge of Cenozoic and historic faulting in the region.

Acknowledgments

This report is a product of a cooperative program of the San Bernardino County Planning Department, the U.S. Geological Survey, and the California Division of Mines and Geology. Mr. Brent Autler of the Planning Department was particularly helpful in coordinating parts of the study. Mr. Larry Rowe of the San Bernardino Municipal Water District supplied information on the current status of ground-water conditions in the San Bernardino area. Messrs. W.R. Moyle and G.A. Miller of the U.S. Geological Survey were of great assistance in locating historic ground-water data. Mr. Moyle first suggested that old photographs might show "offset" orange groves in the San Bernardino area. Mr. D.J. Beeby, California Division of Mines and Geology, Los Angeles District, assisted in the evaluation of 1928 aerial photographs of the area. Discussions of the regional geology with Dr. D.M. Morton of the U.S. Geological Survey, Menlo Park, were very helpful. Dr. Morton compiled the generalized geologic map (plate 1) and prepared the generalized fault (plate 2) and landslide and slope stability maps (plate 3) included in this report. Mr. Charles Bishop, California Division of Mines and Geology, San Francisco District, assisted in interpretation of the liquefaction potential. Many other individuals too numerous to name gave valuable assistance.

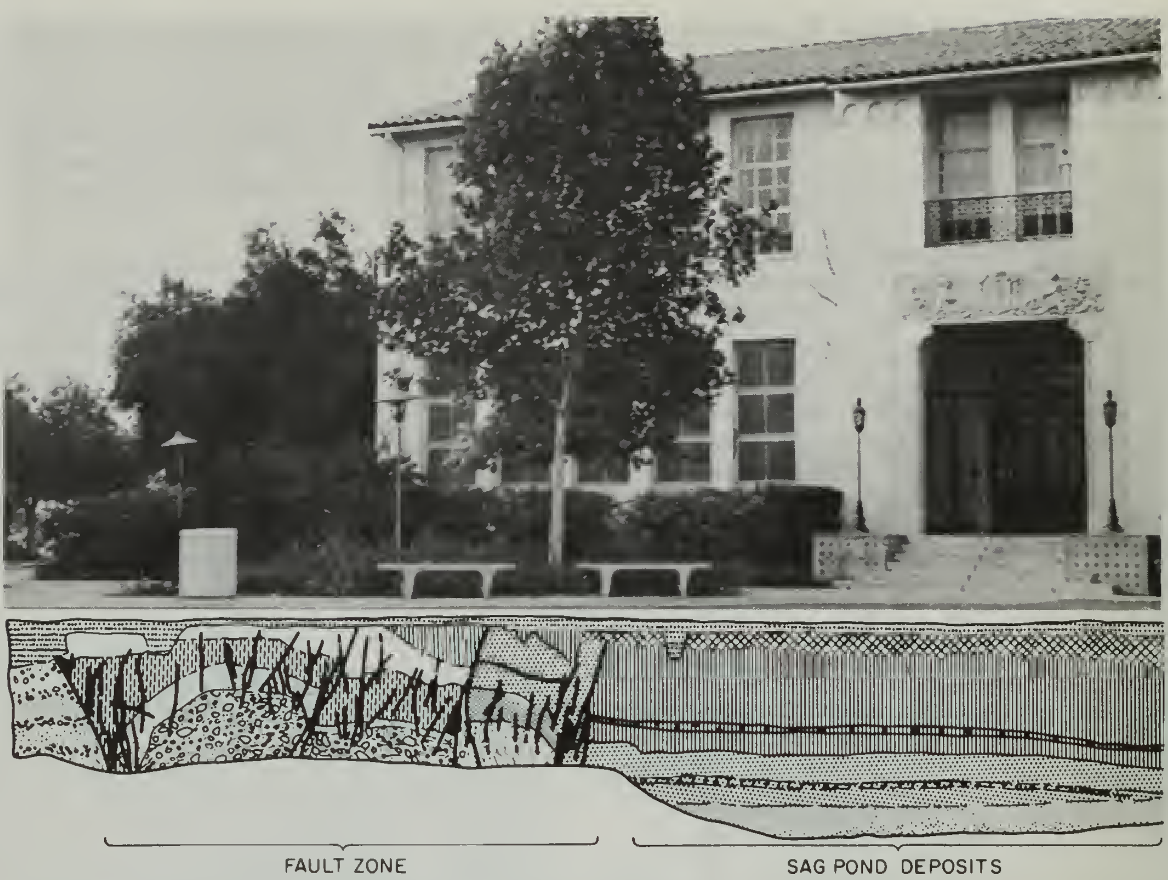


Photo 14 San Jacinto fault zone west of the Life Science Building at San Bernardino Valley College. The fault and sag pond deposits as exposed in the trench are shown in cross section. Photo by Donald L. Fife; trench log courtesy of Converse-Davis & Associates, Pasadena.

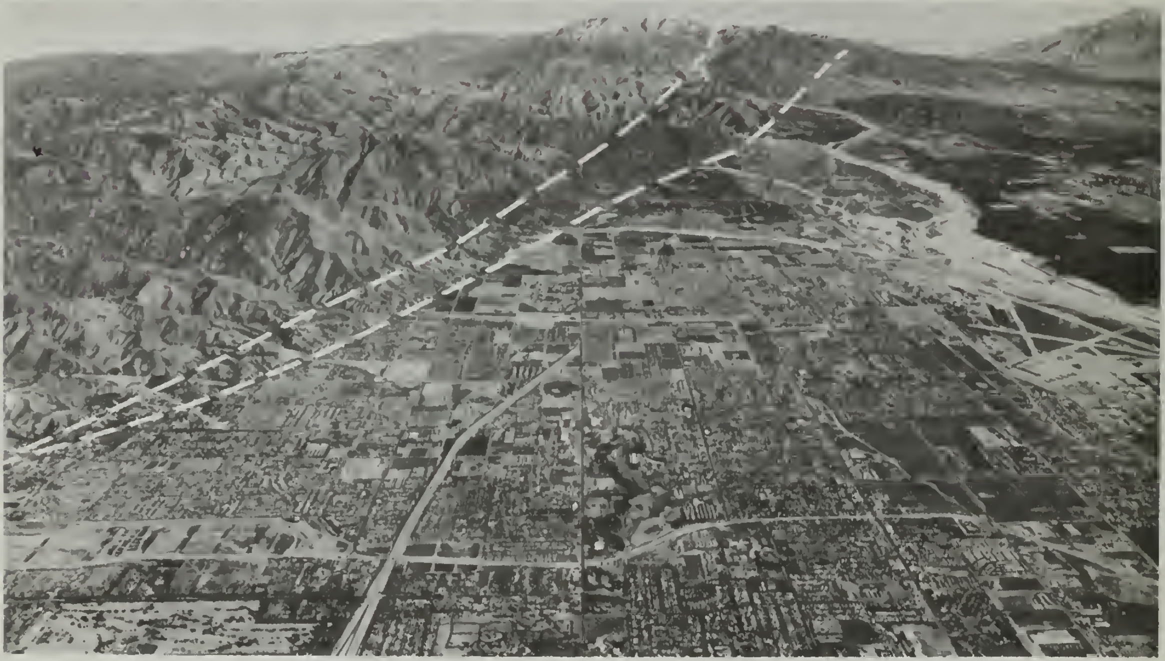


Photo 15. San Andreas fault zone in northeast San Bernardino; view due east. Highland Avenue in the center of the photo bisects the view and points toward Mt. San Bernardino and Mt. San Gorgonio on the horizon. The most recently active trace of the fault delineates a sharp break between the valley and San Bernardino Mountain front (upper left of photo). The trace of a subparallel fault (known as the North Branch of the San Andreas fault) can be seen trending in the same direction slightly higher along the mountains. Note the urbanization along the fault (see photo 16). Photo by Gordon Davis, Aerial Enterprises, San Bernardino.

GEOLOGIC AND STRUCTURAL SETTING

Southwestern San Bernardino County is underlain by several fault-bound structural blocks uplifted during Pleistocene time. These blocks are the Puente Hills on the west, the San Bernardino Mountains on the northeast, and the San Gabriel Mountains on the north (figure 2). Down-dropped blocks are the relatively stable Perris Block and the San Bernardino Valley Block. The Perris Block underlies the Chino basin in the central and southern portions of the area and is bounded on the southwest by the Chino-Corona segment of the Elsinore fault zone and on the northeast by the downdropped San Bernardino Valley Block. The Chino-Corona segment of the Elsinore fault zone, as defined in this report, extends northward from Bedford Wash in the Corona South quadrangle along the northern Santa Ana Mountains and eastern side of the Puente Hills paralleling the Chino and Central Avenue fault zones and is terminated by the San Jose Hills in San Dimas quadrangle on the north. The Chino-Corona segment of the Elsinore fault zone represents a major boundary between the Perris Block and the northern Santa Ana Mountains and the Los Angeles Basin on the west, just as it represents a major break between the Perris Block and the Santa Ana Mountains farther south. The San Bernardino Valley Block underlies the Bunker Hill-San Timoteo Basin and represents a rift between the San Andreas fault zone on the northeast and the San Jacinto fault zone on the southwest. The San Bernardino Valley Block has subsided tectonically and is crossed by a number of minor northeast-trending faults.

In this report the base of fresh water defines the base of the alluvium. The thickness of the alluvium, as shown on plate 5, is determined by the base of fresh water (California Department of Water Resources, 1970c).

For purposes of this report, areas of low permeability and poor water quality, particularly from mineralized thermal springs adjacent to faults, are not included in the alluvium.

The portion of the Perris Block which is covered by the alluvial debris of the San Gabriel Mountains Block probably has an undulating surface much like that of the exposed portions of the Perris Block to the south. The same granitic and moderately high grade metamorphic terrane with marble roof pendants and pegmatite dikes is believed to be present beneath the clastic debris.

Chino Basin

The Chino Basin, which includes the cities of Chino, Upland, Ontario, and Fontana, is a sedimentary basin bounded by major faults and resistant hills. This basin, underlain by the Perris Block, lies southwest of the active San Jacinto fault zone (historic faulting) and east of the Puente Hills and the potentially active Chino-Corona segment of the Elsinore fault zone (Quaternary faulting).

The Chino-Corona segment of the Elsinore fault zone is generally obscured beneath the recent alluvium along the southwest margin of this basin. The northern boundary of the Chino Basin is defined by the steep face of the eastern San Gabriel Mountains and a series of reverse oblique fault scarps belonging to the Cucamonga fault zone, which is part of the active southern Transverse Range fault system. This fault system includes the east-west trending faults (Malibu Coast, Raymond Hill, San Fernando, Sierra Madre, Cucamonga, and Banning faults) associated with Quaternary uplift along the southern Transverse Ranges. The south boundary of the basin is marked by a discontinuous series of resistant granitic and metamorphic hills exposed extensively to the south in Riverside County (figure 2).

The portion of the Chino-Corona segment of the Elsinore fault zone within the study area is about 10 miles (16 km) long and averages 2 miles (3.2 km) wide and may contain a vertical thickness of as much as 8,000 feet (2,440 m) of faulted Los Angeles Basin Tertiary sedimentary rocks in the fault zone near Prado Dam. Near the northern end at the Los Angeles County line, Tertiary sediments within the fault zone become thinner and probably are less than 3,000 feet (900 m) thick (plate 7).

Outliers of Pliocene marine sedimentary rocks are found several miles east of the Chino-Corona segment of the Elsinore fault zone in the vicinity of Norco, indicating transgression of the Pliocene sea, although probably only locally, east of the Elsinore fault system. Faulting along the east side of this fault system probably began in Upper Cretaceous time, and intermittent uplift probably continued at least into Pliocene time. Since the Elsinore fault system has some apparent evidence of historic movement (Engel, 1959), the segment of this fault system at the western margin of the Chino Basin (plate 6) should be regarded as potentially active and the subject of additional study prior to urban development in this area.

The relief between the crest of the San Gabriel Mountains and the base of alluvium near Ontario is more than 10,000 feet (3,000 m). The alluvium averages more than 800 feet (244 m) thick in the central area of the basin, and just northeast of Ontario the maximum thickness is more than 1,300 feet (376 m).

One of the most important zones of artesian ground water in the study area is located on the western margin of the basin between Chino and the Prado Flood Control Basin (plate 4A). The confining layer was estimated to be about 100 feet (30 m) thick near Chino (Garrett and Thomasson, 1949). As in the San Bernardino artesian area, the confining layer(s) were not entirely impermeable and leaked innumerable places, creating marshes and bogs prior to extensive withdrawal of ground water for irrigation.

Bunker Hill-San Timoteo Basin

The Bunker Hill-San Timoteo Basin, which includes the cities of Rialto, Colton, Loma Linda, Redlands, and San Bernardino, lies in the rift between the active San Andreas fault zone on the northeast and the active San Jacinto fault zone on the southwest. Both the San Andreas and the San Jacinto fault zones trend northwest and are roughly 1 mile (1.6 km) wide through the San Bernardino area. The San Andreas fault has been most recently active along an alignment of scarps, trenches, ridges, springs, and offset drainages on the east side of the larger zone and immediately adjacent to the San Bernardino Mountain front. The older-appearing west side of this zone is usually buried by actively accreting alluvial fan deposits. However, alignment of topographic highs, ground-water barriers, and at least one set of magnetic anomalies (plate 8) suggests the presence of this zone. The 1,000-foot (300 m) deep alluvial basin in the fault zone between the mouths of the Santa Ana Wash and Mill Creek Canyon is also suggestive of a relatively wide zone (plate 5-B).

The most active branch of the San Jacinto fault zone, the western branch, is called the Claremont or San Jacinto fault; and within the Colton-San Bernardino area, it is called the Bunker Hill dike. The Rialto-Colton fault or ground-water barrier defines the west side of the Rialto sub-basin, which lies within the northwest trending San Jacinto fault zone. However, the Rialto-Colton fault does not appear as closely related to the San Jacinto fault as the nearly parallel Glen Helen-Loma Linda fault to the east. Magnetic and seismic evidence (plate 8), as well as the geometry of the faults, suggest that the Glen Helen and Loma Linda faults are one and the same fault, or a narrow fault zone, connecting in the subsurface or alluvium beneath the city of San Bernardino. It is highly probable that they are one zone, but from the present study this could not be determined conclusively. Further study will be required to prove the precise relationship and the potential hazards associated with this portion of the fault zone.

A minor set of northeast-trending faults appears to conjugate to the right-lateral slip of the San Jacinto and San Andreas fault zones. These are locally important and commonly form one or more ground-water barriers, such as the Crafton Hills and Chicken Hill faults, in localized sub-basins.

The relief between the crest of the San Bernardino Mountains and the base of alluvium in San Bernardino is more than 11,000 feet (3350 m). The alluvium in the Bunker Hill-San Timoteo Basin has quite variable thicknesses in that the region between the two major faults consists of a series of grabens and horsts with hills protruding above the alluvium. The maximum alluvial thickness is 1,200 feet (366 m) between the National Orange Show grounds and the west end of Norton Air Force Base.

Two distinct lineaments, which suggest historic ground rupture, are evident on 1928 Fairchild aerial photographs of the San Bernardino area. One lineament is subparallel to the San Andreas fault about 1.25 miles (2 km) southeast of Arrowhead Springs and passes just north of the buildings at Mitchell Elementary School. The quality of the photographs is poor; however, one can follow the feature diagonally for about 1 mile (1.8 km) through an orange grove and into adjacent fields. The trees in the grove appear to be displaced along the lineament, and several trees are missing along the trace of the lineament. Possibly new trees were planted between old or diseased trees south of the lineament and the older trees were removed. This is suggested by the smaller size of the trees on the south side of the lineament. Actual displacement of the grove is debatable. However, the lineament definitely indicates some type of ground rupture, possibly occurring during one of the strong earthquakes of 1890, 1899, 1907, or 1923 that originated in the immediate vicinity.

The other lineament is east of and subparallel to the Loma Linda fault and lies about 1 mile east of the Loma Linda Hospital. The 1928 photographs show this feature disturbing the alluvium for about 1.5 miles between the Gage Canal on the north and Mission Road on the south. A projection of this line to the south goes into the Holocene alluvium of San Timoteo Creek and lines up with a projection of the main trace of the Banning fault about 1 mile southeast of the mouth of San Timoteo Canyon. This lineament could be related to some of the subsidence in the Loma Linda area. The feature is still faintly visible on some recent aerial photographs and resembles an abandoned farm road. A projection of this lineament toward the south places it at the subsurface break in slope between the rising basement complex and the gently sloping basal surface of the alluvium (plate 5-B). Although the lineament may be involved in the stress created by local ground-water related subsidence, this does not rule out the possibility of its being a fault. Hadley (1973) has plotted a line of microearthquake epicenters almost precisely along this lineament (plate 2B). Hadley's line of seismic activity extends both north and south from this photographic lineament. Possibly the feature is a fault and represents a transitional feature or segment between the Banning and Loma Linda faults.

LANDSLIDES AND SLOPE STABILITY

Landslides are the result of natural or man-aided erosional processes involving downslope transport of unstable soil and rock. The speed of landslide movement ranges from tens of miles per hour (30-60 kph) for rockfalls, mud flows, and debris flows on steep slopes to intermittent and almost imperceptible creep on gentler slopes. Important factors influencing slope stability are soil and rock types, moisture, climate, rainfall intensity, relief, geologic structure, and human activity.

Many of the large landslides in southern California occurred during the last Pleistocene glacial period

10,000 to 20,000 years ago when the rainfall was significantly greater than at the present time. Many of these landslides are in delicate equilibrium with the present hillside environment and are subject to movement during wet cycles and earthquakes.

Morton (1971) describes extensive surface landsliding (rockfalls and soil slumps) during the 1971 San Fernando magnitude 6.4 earthquake. The 1952 Arvin-Tehachapi magnitude 7.7 earthquake activated extensive surface slides and numerous bedrock landslides. Lawson and others (1908) described numerous landslides of all types resulting from the estimated magnitude 8+ 1906 San Francisco earthquake.

Because inactive landslides are usually in delicate balance with their hillside environment, human activities such as excessive irrigation, road construction, or urban development can upset the equilibrium and initiate slope failure. These same human activities can also create landslides where none has existed before. Probably the greatest hazard results from failure to recognize existing landslides and areas of potential landsliding prior to urban development. Once existing and potential landslide areas are recognized, most can be safely developed, avoided, or removed. Landslide control may then become only a matter of engineering economics.

The landslides and slope stability map (plate 3) was based on unpublished mapping and aerial photographic interpretation by D.M. Morton. The original map was prepared on 7 1/2-minute 1:24,000 scale topographic quadrangles and reduced to 1:48,000 scale. Slopes were generalized: (I) valley floor, (II) areas of low relief, (III) areas of moderate relief, and (IV) areas of high relief. Generalized landslide susceptibility was divided into three categories: (a) generally devoid of landslides, (b) low to moderate, and (c) moderate to high.

Landslide areas designated II-b generally are subject to surficial soil slips, debris flows, and mudflows on local steep areas too small to indicate at map scale of 1:48,000. This would typically include cliffs or bluffs along significant drainages.

Areas designated III-b or III-c and IV-b or IV-c contain rotational slides, block glide slides, and other landslide types of significant size, as well as small surficial slides and flows. Areas designated III-a are subject to occasional rockfalls and rolling boulders, particularly during heavy rains and earthquakes.

All hillside areas warrant geologic analysis, as potential landsliding exists to some degree in almost every hillside area. However, the entire Puente-Chino Hills area, including about 40 square miles of the county, is underlain by landslide-prone marine rocks. This area, designated III-c, probably presents the greatest potential slope stability problem in the study area.

In areas identified as landslide prone, no development should be permitted prior to detailed geologic and soils analysis and the performance of engineering measures required to stabilize each building site. In many localities of unstable slopes, larger structures or developments become more feasible than smaller structures or developments, since the smaller return on a smaller project will not justify the predevelopment costs.

To a lesser degree than in the Puente-Chino region, the steep mountain fronts of the eastern San Gabriel and southwestern San Bernardino Mountains present a major stability hazard, particularly those areas adjacent to the San Andreas and Glen Helen fault zones where large masses of incompetent rock are elevated in shear zones.

Since these areas lie within the National Forest, it is assumed they will not be developed. Landslide areas, such as the Mill Creek area, may present major problems in highway construction and maintenance, and debris may cause rapid filling in flood control structures downstream. Landslide areas, labeled III-c on plate 3, could have serious effects on large dams and/or reservoirs for water storage or electrical power generation, or even on appurtenant pipelines and transmission lines (Fife, 1968).

Landslide deposits are frequently source areas for large debris flows or mudflows occurring during periods of heavy rainfall, particularly after the vegetative cover has been stripped by fire.

GROUND WATER

Water-Table Conditions, 1880-1972

The western margin of the basin between Chino and the Prado Flood Control Basin contains one of the most important zones of artesian ground water in the study area (plate 4A). The confining layer was estimated to be about 100 feet (30 m) thick near Chino (Garrett and Thomasson, 1949). As is also true in the San Bernardino artesian area, the confining layer(s) in the Chino basin were not entirely impermeable, and seepage in innumerable places created marshes and bogs prior to the extensive removal of ground water for irrigation. Plates 4A and 4B depict the high water table of the late 1800s just before the impact of irrigation and urban demand on the local water resources. During the late 1800s Etiwanda Creek flowed perennially 5 miles out of the mountains to the valley floor near the present site of the Kaiser Steel Company mill. Lytle Creek flowed perennially from the north of Lytle Creek canyon to the San Ana River.

On depth-to-ground-water maps, plates 4A and 4B, the contours southwest of the San Jacinto fault zone show the depth to water for fall 1960 (California Department of Water Resources, published maps, 1970a), and contours northeast of the San Jacinto fault show the depth to water for fall 1972 (Lavarty, unpublished data, 1973).

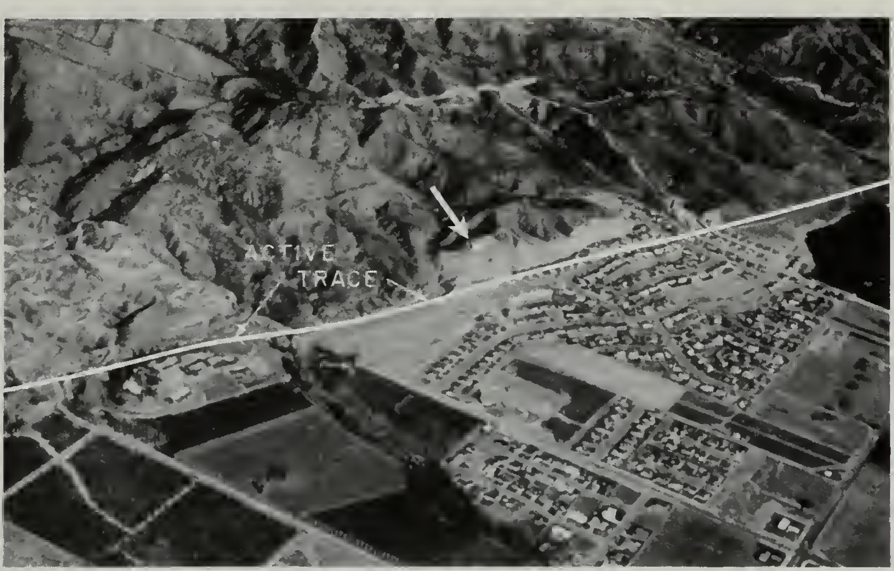


Photo 16. Urban expansion into the San Andreas fault zone near Waterman Canyon. Note the potential hazard from water tank failure above subdivision (arrow). Photo by Rasmussen and Associates, Rialto.

Photo 17. Landslide in marine sedimentary rocks of the Puente Hills. The casual observer may miss the subdued outline and low profile of the landslide. Probably the greatest hazard results from failure to recognize existing landslides and areas of potential landsliding prior to urban development. Photo by Donald L. Fife, 1974.

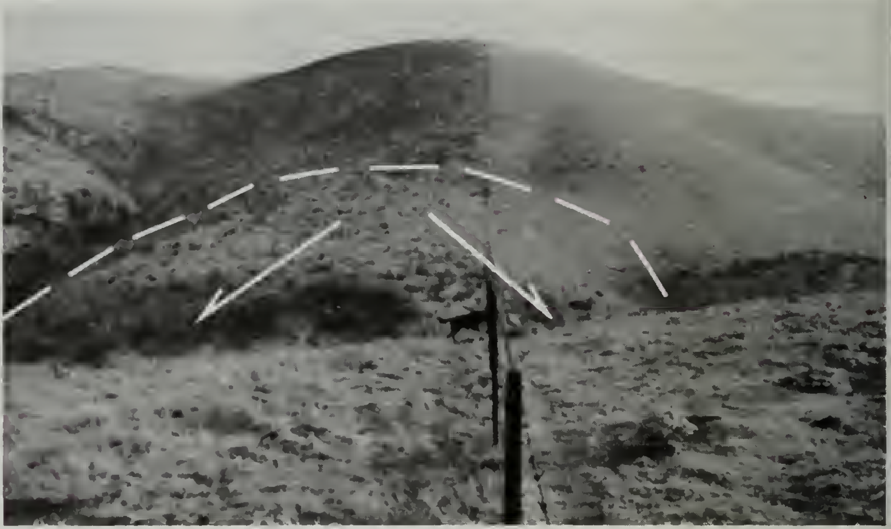


Photo 18. Close-up of small landslide shown in photo 16. The slide, which is poorly defined in the upper portion, has diverted the drainage and practically blocked the canyon. If the potentially hazardous areas are recognized in the planning stage, they can often be safely developed, avoided, or removed. Photo by Donald L. Fife, 1974.

The depth to ground water fluctuates and varies in lation to precipitation and ground-water manage- ent. Plates 4A and 4B illustrate the typical condition f lower water level resulting from the great demand r water in the last few decades.

The high water-level conditions shown on plates A and 4B will not return as long as the Upper Santa na Valley remains as populous as today. However, uring very wet years, there will be short periods when wland areas will be subjected to standing surface ater and shallow-water tables. One problem com- icating ground-water management is that artesian uifers apparently act as hydraulic systems. The water vels rise hydraulically in the lower end of the con- ned aquifer soon after the water enters the upslope ea of infiltration. This is contrasted with water flow- g in a normal free ground-water table, where it may ke 1 to 4 years to affect the downslope water level.

In the Bunker Hill-San Timoteo Basin, the San ernardino Municipal Water District will manage the ater supply starting in 1978 by storing imported water ground water in the alluvium east of the San Jacinto ult. This ground water can pass over the fault into the Santa Ana River whenever the water level rises to approximately the 980-foot (300 m) elevation (Woodward-Lundgren and Associates, 1973a,b,c). When the ground water reaches about the 1030-foot (314 m) elevation near the Santa Ana River channel, springs develop and the ground water passes downstream over the San Jacinto fault and out of the local water district. The water district will control the imported water to prevent unnecessary loss over the 1030-foot (314 m) elevation because water rising above this level may create flooding of basements and shopping areas in the lower portions of San Bernardino. Loss of ground water would also be loss in revenues to the Water District.

Liquefaction Hazard

Inspection of the U.S. Corps of Engineers and San Bernardino County Flood Control District's excavations for the Lytle Creek-Warm Springs project through the downtown San Bernardino and adjacent areas during the summer of 1973 revealed numerous areas of perched water tables. Perched water tables usually are within 5-20 feet (1.5-6 m) below the surface

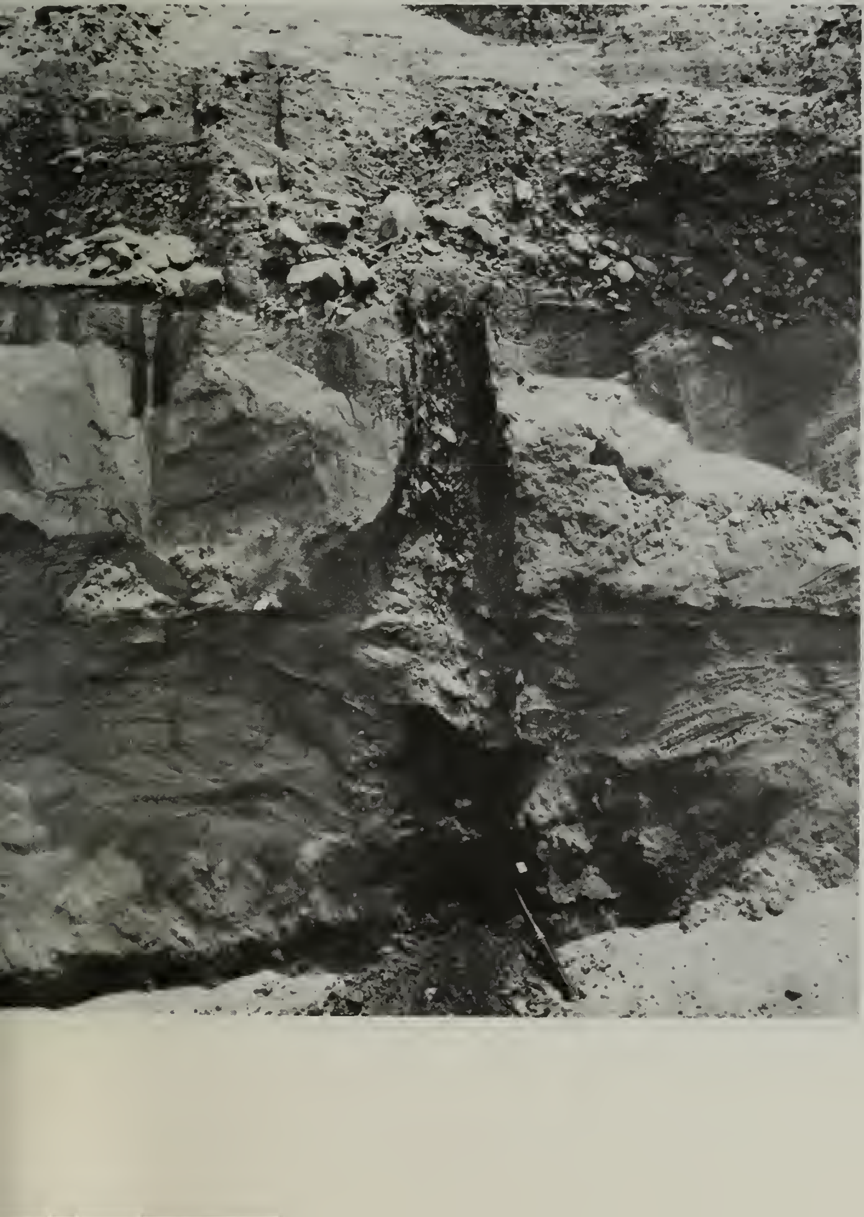
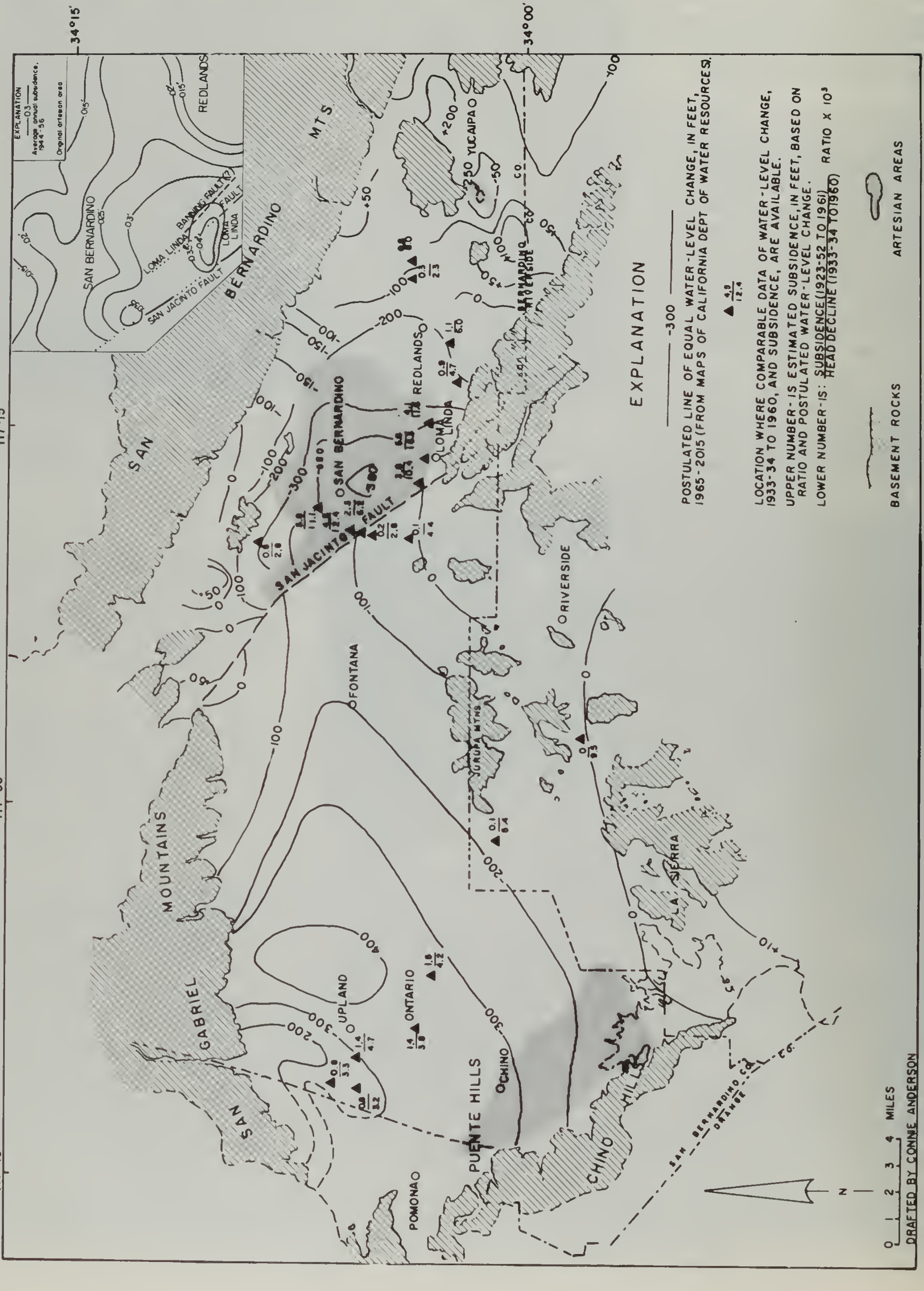


Photo 19. Probable evidence of a seismically induced "sand boil" suggesting liquefaction conditions in Colton-San Bernardino area before urbanization. The unconsolidated sands and gravels shown here are typical of the alluvial filled channels in the San Bernardino area and represent a liquefaction hazard when saturated. Photo by Oscar Huber, Riverside, 1971.


34°15'
34°00'
117°15'
117°30'
117°45'
EXPLANATION
.03
Average annual subsidence, 1944-56
Original artesian area
SAN BERNARDINO
REDLANDS
LOMA LINDA
BANNING FAULT (?)
LOMA LINDA FAULT
SAN JACINTO FAULT
SAN BERNARDINO MTS
SAN GABRIEL MOUNTAINS
PUENTE HILLS
CHINO HILLS
JURUPA MTNS
LA SIERRA
YUCAIPA
RIVERSIDE
FONTANA
UPLAND
ONTARIO
CHINO
POMONA
SAN JACINTO FAULT
SAN BERNARDINO CO.
ORANGE CO.
SAN BERNARDINO CO.
RIVERSIDE CO.
EXPLANATION
-300
POSTULATED LINE OF EQUAL WATER-LEVEL CHANGE, IN FEET, 1965-2015 (FROM MAPS OF CALIFORNIA DEPT OF WATER RESOURCES).
4.9 / 12.4
LOCATION WHERE COMPARABLE DATA OF WATER-LEVEL CHANGE, 1933-34 TO 1960, AND SUBSIDENCE, ARE AVAILABLE.
UPPER NUMBER-IS ESTIMATED SUBSIDENCE, IN FEET, BASED ON RATIO AND POSTULATED WATER-LEVEL CHANGE.
LOWER NUMBER-IS: SUBSIDENCE (1923-52 TO 1961) / HEAD DECLINE (1933-34 TO 1960) RATIO x 10³
BASEMENT ROCKS
ARTESIAN AREAS
MODIFIED FROM B.E. LOFGREN (1971)
0 1 2 3 4 MILES
DRAFTED BY CONNIE ANDERSON
N

d result from irrigation of lawns and other urban es. The area affected by the shallow, perched water is tremely varied and impossible to map adequately on e regional scale of the present study. However, in the ent of a major earthquake, these areas of perched ater present a liquefaction hazard, particularly to rge structures. The areas of possible hazards can be aluated only by detailed site investigation.

Comparisons between water levels in 1880 and 60-70 (plates 4A and 4B) show the immense change the water table over a period of 75 years. Most of the arshes or areas of permanent standing water in the lley during the late 1800s were at least partially the sult of leakage from the artesian aquifers. One neficial result of the lowering of the water table over e last 75 years has been the reduction of the liquefacn hazard in the lowland areas. However, lowering of e water table has produced subsidence.

SUBSIDENCE

Subsidence has become apparent in many parts of alifornia since about 1940. The principal cause has een the removal of large volumes of subsurface fluids, articularly oil and water. This man-induced subsience may occasionally be superimposed on tectonic bsidence commonly associated with large sedimenry basins in seismically active regions like southern alifornia. Poland and Davis (1969) and Lofgren 965) have summarized the mechanics and case histoes of subsidence.

Thick, poorly consolidated alluvial deposits, such s those found in rapidly filling basins in southern alifornia, may be subjected to subsidence if a large olume of water is removed. Even relatively small perentages of montmorillonite clay, micaceous minerals, r organic debris, if present, will increase the ossibilities for subsidence. One of the greatest potenial subsidence problems involves aquifers within arteian areas. The amount of subsidence that a confined quifer system will experience is a function of soil paricle size, shape, and mineralogy; geochemistry of pore ater and of water in contiguous aquifers; and comression (Poland and Davis, 1969).

Subsidence may be alleviated by: (1) stopping withrawal of fluids, (2) restoring aquifer pressure by slowg withdrawal, or (3) repressuring with fluid injection.

The effects of local subsidence in the Upper Santa na Valley region were first noticed in the mid-1960s. ofgren (1971) and Miller and Singer (1971) reviewed he available leveling and ground-water data in order define the magnitude and location of subsidence as f 1970 and to assess the potential for further subsidnce. As with other southern California areas where round water has been mined—that is, more water has een extracted than is replenished naturally—subsidnce was confirmed. It was found that at least 1 foot of ubsidence had occurred in the artesian area imediately north of Loma Linda between the San Jacin and Loma Linda faults (figure 3).

Lofgren (1971) addressed his study to postulated lowering of the water table through partial mining and the effect of lowering the ground water during the period 1965-2015 in the Upper Santa Ana Valley. He was limited by lack of ground-water data and particularly by the lack of first-order survey data. Figure 3 summarizes his findings. The Upland-Ontario area could have from 0.8 to 1.5 feet (0.24-0.45 m) of subsidence. Generally, the greater the lowering of the water table, the greater the amount of subsidence. The areas where further subsidence can be expected roughly correspond to the areas underlain by the thicker alluvium (shown on plates 5A and 5B) or by highly compressible artesian aquifers (shown in detail on plates 4A and 4B). The greatest potential for subsidence, 5.8 feet (1.78 m), is indicated for the former artesian area just north of Loma Linda.

As a result of the studies of estimated subsidence as well as other considerations, local San Bernardino agencies have chosen to spread sufficient imported water to recharge the ground-water aquifers to about 1940 water levels (Rowe, personal communication, 1973) and thus halt or impede further subsidence. Stored water might also help alleviate a water shortage if the imported supply was interrupted during a significant earthquake.

Probably several parts of the study area have undergone subsidence during earlier years of heavy ground-water withdrawal. Large cracks formed in the Yucaipa area in the years following heavy withdrawal of water for irrigation (Burnham, personal communication, 1973). The cracks could have been the result of ground water withdrawal or possibly hydrocompaction. About 600 acres (240 hectares) are underlain by artesian aquifers in Yucaipa.

A north-south trending fissure immediately north of the California Institution for Men at Chino lies within the Chino-Prado artesian belt and probably represents an active subsidence feature (Morton, personal communication, 1974). This suggests that the 12,000 to 14,000 acres (4,900 to 5,700 hectares) overlying the old artesian belt has subsided or is undergoing subsidence. An area of 11,000 to 17,000 acres (4,500 to 6,900 ha) overlies the San Bernardino artesian area, which may be subsiding.

Within the study area, there is not enough information to provide the true detailed picture of subsidence problems. More first-order surveys, field investigations, and ground-water studies are needed to identify hazardous subsidence areas.

Subsidence affects structures sensitive to slight changes in elevation, such as highways, canals, pipelines, drains, sewers, and particularly hydraulic structures subject to high pressures. Subsidence commonly occurs in such slight magnitude and over such large areas that it is not perceptible to an observer unless there is a means of reference. Change is usually uniform over a large area and does not generally cause damage to relatively small structures.

Surface displacement along pre-existing fault planes has been reported in Texas (Poland and Davis, 1969) and in the San Jacinto Valley 15 miles (24 km) south of the study area (Fett and others, 1967). Subsidence in these areas is associated with ground-water withdrawal along pre-existing fault planes. Surface displacement has caused large cracks to develop which damage structures situated across them. Similar vertical displacements are a possibility in the study area if subsidence is allowed to continue. In subsiding areas, shaking during an earthquake would probably result in lurch cracks and acceleration of the consolidation process.

GEOPHYSICAL SURVEYS

The objective of the geophysical program conducted as part of the geological investigation in the San Bernardino area was to locate concealed segments of the San Andreas, San Jacinto, Glen Helen, Loma Linda, Chino, and possibly other fault systems beneath the alluvium in selected areas and to determine fault trends and thickness of alluvium.

Geophysical Data

Geophysical data discussed in this report consist primarily of the results of magnetic and seismic surveys conducted in the San Bernardino Valley area by the California Division of Mines and Geology (plate 8). A regional gravity study of the San Bernardino area (Willingham, 1968) and a few gravity profiles located in the northern part of the area (California Department of Water Resources, 1966) were also used. Since the geophysical work was done in limited areas, it is very likely that additional geophysical work would reveal further evidence of buried faults.

Magnetic Survey

Method

A Jalander vertical component magnetometer with a maximum reading sensitivity of 10-15 gammas was used for the survey. Approximately 20 miles (32 km) of line was traversed using 100-foot (30 m) station intervals (plate 8). Many of the lines were located in the Lytle Creek-Cajon Creek wash and the Santa Ana River area. Traverses (M-7 and M-9) were run near Patton State Hospital to detect branches of the San Andreas fault. One long traverse (M-8) was run across the Prado Flood Control Basin to check for the possible extension of the Elsinore fault system and other faulting that had not been previously identified.

Results

Many magnetic anomalies discussed in this report are abrupt changes in magnetic intensity levels. Some of these anomalies are as much as 200 gammas in amplitude, but most are less than 100 gammas. These relatively sharp changes suggest a magnetic source less than 500 feet (150 m) in depth and perhaps even present at ground surface. Other anomalies show forms typical of deeper-seated sources. Anomalies in man parts of the area were caused by man-made structure even though an attempt was made to avoid these object in the field.

In the southern portion of the area in and near th Santa Ana River wash, several sharp changes of magnetic intensity levels are shown on each of three magnetic lines (M-1, M-4, and M-5), suggesting differenc in type of alluvium, and possibly faulting. On one lin (M-1) at least three of these anomalies appear to be located above possible traces of the San Jacinto fau (anomalies 1 and 2) and the Loma Linda fau (anomaly 3). The magnetic high shown between thes two faults on line M-1 could indicate a thickening the alluvium or shallower than normal bedrock.

The exact position of anomaly 3 on line M-1 unknown due to interference from the Waterman Roa overcrossing structure. However, its approximate location suggests it may mark the Loma Linda fault. O line M-4 the magnetic intensity level change anomaly is probably correlative with anomaly 3 on line M- This alignment corresponds approximately to a poss ble trace of the San Jacinto fault. The three anomalie labeled 1 on lines M-1, M-4, and M-5 may possibly b the magnetic indications of a branch of the San Jacint fault even though the level change at anomaly 1 on lin M-4 is in the reverse direction compared to the othe two.

In the Lytle Creek and Cajon Creek washes, line M-2 and M-6 extend northeasterly from Riversid Avenue toward the San Andreas fault system. Line M- is farther southeast and is in the Lytle Creek drainag In the southwest part of line M-6 southwest of Verdemont Boys Ranch, a broad magnetic high peaks nea Station 2000. The sharp change in magnetic intensity anomaly 1 on line M-6 just northeast of the ranch appears near the alluvium-granite contact and indicate either a fault at this location or alluvial material, whic is more magnetic than the granite. Two othe anomalies, 2 and 3, at the extreme northeast end of lin M-6, are thought to be magnetic indications of tw traces of the San Andreas fault system. Anomaly 4 o line M-6 is not easily recognizable because of inte ference from other anomalies, but its location ma mark a trace of the Glen Helen fault. On magnetic lin M-2, the magnetic anomaly identified as 1 is immediately northeast of Interstate 15. This is believed t indicate a fault, but the trend of the presumed fault unknown. Anomalies 2, 3, and 4 probably represen multiple traces of the San Andreas fault system. Tw distinct magnetic-level changes occur on line M- namely anomalies 1 and 2, which may indicate faul traces of the San Jacinto system.

Two magnetic traverses (M-7 and M-9) on eithe side of Patton State Hospital, each show one dominan anomaly, numbered 1. These magnetic intensit changes are probably caused by a trace of the Sa Andreas fault system. Anomaly 2 on line M-9 coul represent a change in the type of alluvium, possibly du to a fault.

Magnetic traverse M-8 crosses the Prado Flood Control Basin. The magnetic intensity values show a general increase from the west end of this line (surface race of the Chino fault) towards the east with a sharp ncrease at Station 11000, a maximum intensity near Station 13000, and a return to the base level at about Station 16000. The relatively large anomaly located between anomalies 3 and 4 on this line on plate 10 probably represents near-surface crystalline basement resulting from near-vertical uplift of crystalline rock along the west margin of the Perris Block (plate 6, Geologic Section D-D′). The two anomalies on the west half of the line, 1 and 2, may represent additional faults of unknown significance within the Chino-Corona segment of the Elsinore fault zone.

Magnetic line M-10, in the Loma Linda area, is parallel to and about 100 feet (30 m) north of seismic line S-7. No magnetic anomalies were identified even though the Loma Linda fault is projected through this area.

Gravity Data

Gravity data in the San Bernardino Valley area were compiled and interpretated by Willingham (1968). He utilized a two-dimensional analysis of the gravity data to estimate the configuration of the basement rock surface beneath the valley and to locate the position of the major faults. An examination of his study indicates that the basement rock configuration presented is only approximated. In fact, Willingham (1968, p. 38) notes an error of approximately 1,000 feet (300 m) at one point. The primary reasons for this lack of accuracy are probably insufficient subsurface control and the presence of basement rocks that are characterized by large differences in density.

An attempt was made to improve the analysis of the gravity data by utilizing a three-dimensional interpretational technique to determine basement rock configuration more accurately. This was found to be impractical, however, because of the limited geological control. Additional subsurface control data, either drill hole or seismic or both, and detailed gravity stations are needed before a more accurate interpretation of the present data can be prepared.

A few detailed gravity profiles were surveyed by the California Department of Water Resources (1966) in the northern part of the study area between the Shandlin Hills and Verdemont. Two gravity lines show anomalies, each about 1 milligal or less in amplitude, that may represent the Glen Helen-Loma Linda fault (lines I and IV, plates 6 and 7, Department of Water Resources, 1966). The anomaly on line I corresponds closely to a magnetic anomaly 4 on line M-6 (plate 8), and the anomaly on line 4 corresponds to seismic anomaly 1 on line S-3 (plate 8).

Seismic Refraction Survey

Method

The seismograph used was a Midwestern Geophysical Laboratory instrument produced in the early 1950s. It consists of three separate units: a high-voltage power supply, an amplifier, and an oscillograph (camera) which recorded on 6-inch (15.2 cm) wide sensitive paper. A geophone cable was connected to the amplifier unit. In the configuration used, the cable was 550 feet (167 m) long with geophone stations at 50-foot (15 m) intervals.

The energy source for this program was a 375-pound (170 kg) steel cylinder which was dropped from a height of 4 feet (1.22 m) onto a 16 x 16 x 1 inch (41 x 41 x 2.5 cm) steel ground coupling plate. The coupling plate was positioned about 4 inches (10 cm) from the end geophone, giving an effective zone time reference.

The seismic traverses were aligned as nearly perpendicular to the expected fault alignment as could be reasonably accommodated in the field. Most of the traverses were about 0.25 mile (0.4 km) in length.

If data were weak or noisy on the far geophones, several options were available. Some stations on the existing cable could be removed to obtain, for example, a 9-station spread, or a shorter length cable could be used with closer geophone spacing, for example, a 275-foot (84-m) cable with 25-foot (7.6-m) geophone spacings. Both alternatives were tried with general success.

Results

Layers with three dominant seismic velocity ranges were detected, as shown on the seismic sections. The severely weathered near-surface velocity layer, 1000-2000 feet per second (fps) (300-370 mps), varies in thickness from about 15 to 50 feet (4.6-15 m). The intermediate velocity layer, 2000-2500 fps (600-760 mps), underlies the near-surface layer and apparently is dry, rather loosely compacted alluvium with a thickness of about 50 to 150 feet (15-46 m). The highest and deepest velocity layer observed, 6000-8000 fps (1800-2400 mps), could be a consolidated sandstone or shale, occurring at a minimum depth of approximately 40 feet (12 m) at Glen Helen Regional Park and reaching a maximum depth of 200 feet (60 m) as determined on line S-2 at Muscoy. The 4000 fps (1200 mps) velocity layer detected on line S-3 could be compacted older alluvium or terrace material or a highly fractured rock unit, such as decomposed granite.

Seismic line S-1 crosses the Glen Helen fault (anomaly 1), as shown by a 10-foot (3 m) vertical displacement of the 8000 fps (2400 mps) layer. The local alluvium was 35 to 40 feet (11 to 12 m) thick west of the postulated fault and 45 to 50 feet (14 to 15 m) thick east of the fault. Also, the velocity of the intermediate layer (second below surface) is shown as increasing from 5500 fps to 7500 fps (1680 mps to 2290 mps) as one crosses this postulated fault, east to west. This velocity change suggests a change of rock type, or possibly the same rock type with one side being sheared or crushed causing a lower seismic velocity.

Two lines in the Muscoy area (S-2 and S-3) were both 1650 feet (500 m) in length with east-west trend.

On each of these lines, the deepest layer terminated west of Station 550. This termination (anomaly 1 on both lines) was considered as evidence of faulting. The depth to bedrock on line S-2 was 200 feet (60 m). The top of the deepest refracting layer on line S-3 was slightly deeper than 100 feet (30 m). This 4000 fps (1200 mps) layer normally would not be considered bedrock, although it could be a highly weathered basement rock.

The interpretations of two seismic sections in the city of San Bernardino (S-4 and S-5) are based on very limited data. Reliable data were used to determine the depth to the top of the intermediate layer 2000 fps (1600 mps). The depth to this layer, which is probably dry alluvium, was in the range of 15 to 25 feet (4.6 to 7.6 m). Below this layer, a limited amount of poor-quality data indicated the presence of a deeper 6000-8000 fps (1800-2400 mps) layer, and suggested subsurface changes which could represent faulting. The anomalies identified as 1 on each line mark the location of possible faults.

Near Tri-City Airport, line S-6 had a consistent 5000-fps (1500-mps) velocity layer at a depth of 50 to 60 feet (15 to 18 m), from Station 0 to Station 1100. This 5000-fps (1500-mps) layer may be coincident with the water table depth. The termination of this layer, anomaly 1, just east of Station 1100, may represent the Loma Linda fault. It was only 500 to 700 feet (150 to 210 m) southeast from a significant magnetic anomaly on magnetic line M-1, in the vicinity of Waterman Street overcrossing.

Seismic line S-7, southeast of the Loma Linda County Hospital, crossed the projection of the Loma Linda fault. The deepest layer reached by the seismic survey on this line had a velocity of about 4000 fps (1200 mps). Depths and velocities of the shallower refracting layers are believed to be accurate. If the fault underlies seismic line S-7, it was not detected.

Because all of the seismic refraction lines except S-7 show evidence that may represent faults, a line representing the possible Glen Helen-Loma Linda fault trend was drawn through the anomalous points from S-1 to S-6 (plate 10).

Additional Work

Additional seismic refraction traverses should be made along the Glen Helen-Loma Linda fault trend. Additional traverses are needed to fix its position, to detect possible splits and offshoots, and to locate other buried portions of the San Jacinto fault system, especially in the alluviated areas.

If the seismic lines are to be located in the Lytle Creek, Cajon Creek, or Santa Ana River washes, portable seismic equipment and high-energy nonexplosive or explosive energy sources would be needed. An additional nonexplosive refraction program might be planned on a trial basis. The lines should be located several blocks away from freeways and heavily traveled roads to avoid spurious high noise levels.

SEISMICITY

Damaging Historic Earthquakes

The area has been subjected to numerous damaging events in the last 200 years, including the 1857 Fort Tejon earthquake, one of the largest events in California's history (table 1). In addition, much damage in the study area has been caused by earthquakes originating outside the area. This area will undoubtedly continue to sustain damage from earthquakes.

Table 1. Historic earthquakes greater than Modified Mercalli VI, 1769-1972.

Date	Estimated epicenter	Estimated or observed intensity at epicenter	Local magnitude	Damage
1769 July 28	Unknown		8(?)	Unknown.
1812 Dec 8	Offshore	VIII-IX	-	Mission San Gabriel, Los Angeles County.
1812 Dec 21	Off Santa Barbara coast	X	-	Probably would have caused damage.
1852 Nov 27-30	Big Pine fault	X(?)	-	Surface faulting(?) in Lockwood Valley. Could have damaged San Bernardino.
1855 July 10(11?)	Unknown	VIII	-	Mission San Gabriel, Los Angeles County. Could have damaged San Bernardino.
1857 Jan 9	35°N., 119°W., near Fort Tejon on San Andreas fault	X-XI	8+ (estimated)	San Bernardino; possible fault breakage on San Andreas and San Jacinto faults.
1889 Aug 27	34°N., 118°W.	VI	-	Pomona; probably also in study area.
1890 Feb 9	34°N., 117.5°W. (on San Jacinto fault)	VI+	-	Pomona; probably also in study area.
1899 July 22	34.5°N., 117.5°W. (on San Andreas fault)	VIII	-	San Bernardino, Highland, and Patton; and near Mitchell Elementary School(?).

Table 1. Historic earthquakes greater than Modified Mercalli VI, 1769-1972. (continued)

Date	*Estimated epicenter*	*Estimated or observed intensity at epicenter*	*Local magnitude*	*Damage*
1899 Dec 25	33.5°N., 116.5°W. (on San Jacinto fault)	IX	-	Study area. Landslides, lurch cracks, and probable surface faulting near Hemet, Riverside County.
1907 Sept 19	34°N., 117°W. (on San Andreas fault)	VII	-	San Bernardino, Redlands, and San Jacinto.
1918 April 12	33.75°N., 117°W. (on San Jacinto fault)	VI-VII (in San Bernardino, Redlands, and Riverside)	6.8	Damage centered in San Jacinto Valley. Lurch cracks in downtown San Jacinto; possible surface faulting.
1918 April 22	34°N., 117.5°W. (on Whittier fault, Elsinore fault)	VI		Corona; probably also study area.
1923 July 22	34°N., 117.25°W.	VII (in San Bernardino, Patton, Harlem Springs, and Redlands)	6.25	Damage to schools in San Bernardino.
1930 Jan 15 (2)	34.2°N., 116.9°W.	VII (VI near San Bernardino)	5.2 and 5.1	Study area.
1948 Dec 4	33.9°N., 116.4°W. (on San Andreas fault)	VII (VII near Desert Hot Springs; VI in San Bernardino)	6.5±	Study area.
1965 April 15	34.7°N., 117.5°W. (San Andreas fault)	VI (VI in San Bernardino Valley)	4.5	Study area.
1968 April 8	33.2°N., 116.1°W.	VII (VI in study area)	6.4	Study area.
1970 Sept 12	34.3°N., 117.5°W. (San Andreas or San Jacinto faults)	VII (VI-VII throughout study area)	5.4	Study area.
1971 Feb 9	34.4°N., 118.4°W. (San Fernando fault)	VIII-XI (VI in study area)	6.4	Study area. Masonry water tank on Yorba-Slaughter Ranch collapsed. Damage to plaster in Colton and San Bernardino.

Adapted from Coffman and von Hake (1973), Hileman and others (1974), Townley and Allen (1939), Richter (1958), and Scott (1971).

Instrumental Data

Plate 7 shows epicenters of earthquakes with magnitude 4 and greater that occurred in southern California from 1910 through 1971. The epicenters were compiled from lists by the University of California Seismograph stations and the Seismological Laboratory of the California Institute of Technology. The accuracy of the epicenters shown on this map varies from several tens of kilometers for the earlier events to a few kilometers for most of the more recent events. The larger events can be identified by their aftershock sequences, and there is a vague tendency for the major faults to be identified on the basis of earthquake epicenters. This may be due to inaccuracy in locating the epicenters. A cluster of magnitude 4 or 5 earthquakes occurs at the junction of the San Andreas and San Jacinto faults near San Bernardino. The inset to plate 7 shows the events of magnitude 4 and greater in the San Bernardino area. In general, seismicity of this magnitude level is fairly low in the study area. Thus, based solely on the available epicenter data, it is not possible to identify those faults in the study area which exhibit current seismic activity.

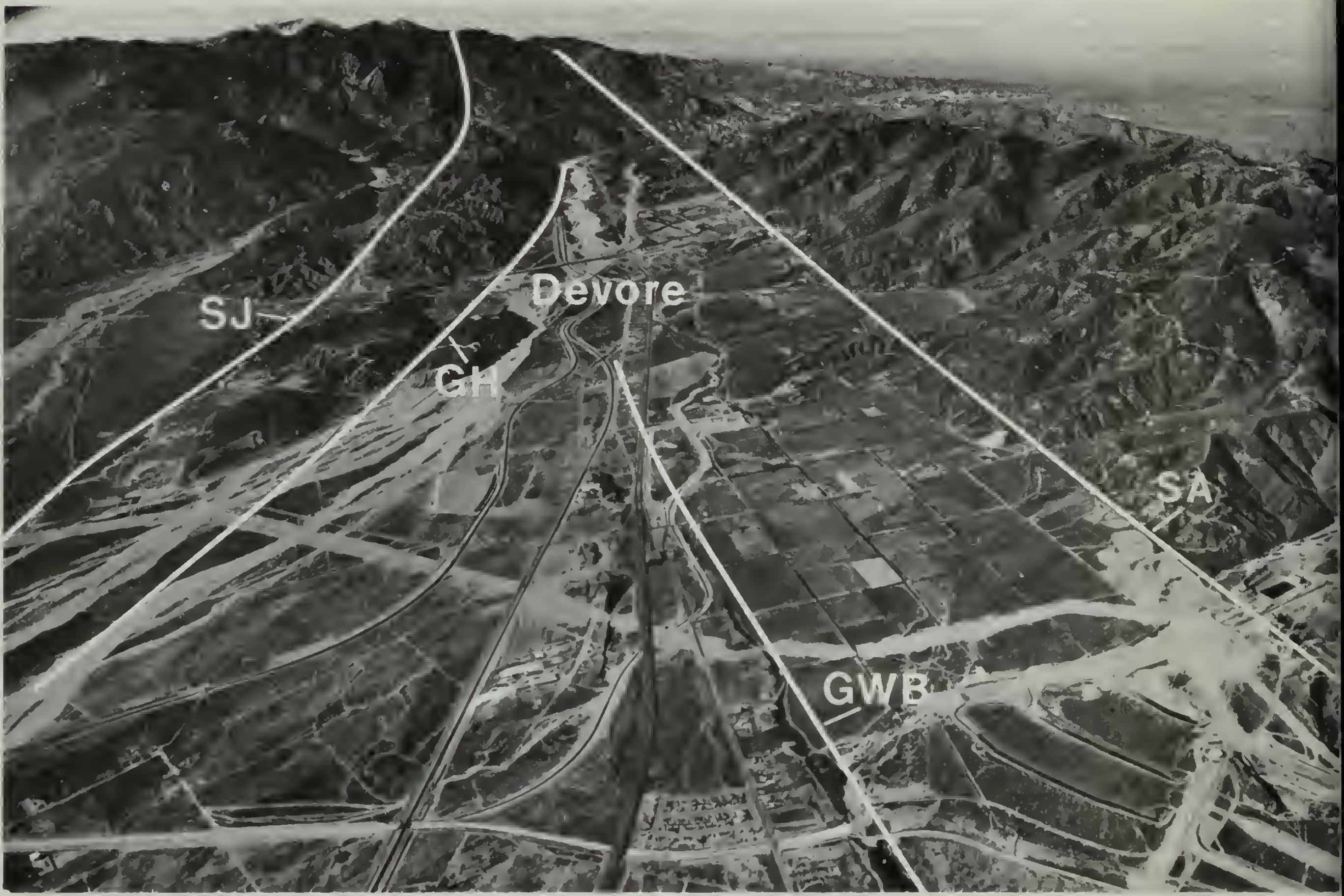


Photo 20. Cajon Pass, point of separation for the San Jacinto fault zones; view northwest. At this juncture, the San Jacinto fault zone (SJ), including the Glen Helen fault (GH), is about 1 mile wide. On the right, the San Andreas fault zone (SA), including poorly mapped groundwater barriers (GWB) on the west side of the most active trace, is about 1 mile wide. Northwest of this point, the San Jacinto and San Andreas faults are essentially parallel and form a wide zone terminating near Palmdale. The faults diverge and are about 25 miles (40 km) apart at the latitude of Indio, 75 miles (120 km) to the southeast. Photo by Gordon Davis, Aerial Enterprises, San Bernardino.

FAULT MOVEMENT

From 1964 to 1966, thirty small survey figures were established by the California Department of Water Resources and the U. S. Geological Survey across faults of the San Andreas system in central and southern California, and most of these figures have been resurveyed several times since they were established. The survey figures are used to detect possible fault creep near the survey sites. Three of these figures—DEVIL, RIALTO, and COLT—were in the study area. DEVIL is on the San Andreas fault, and RIALTO and COLT are on the San Jacinto fault (plate 2).

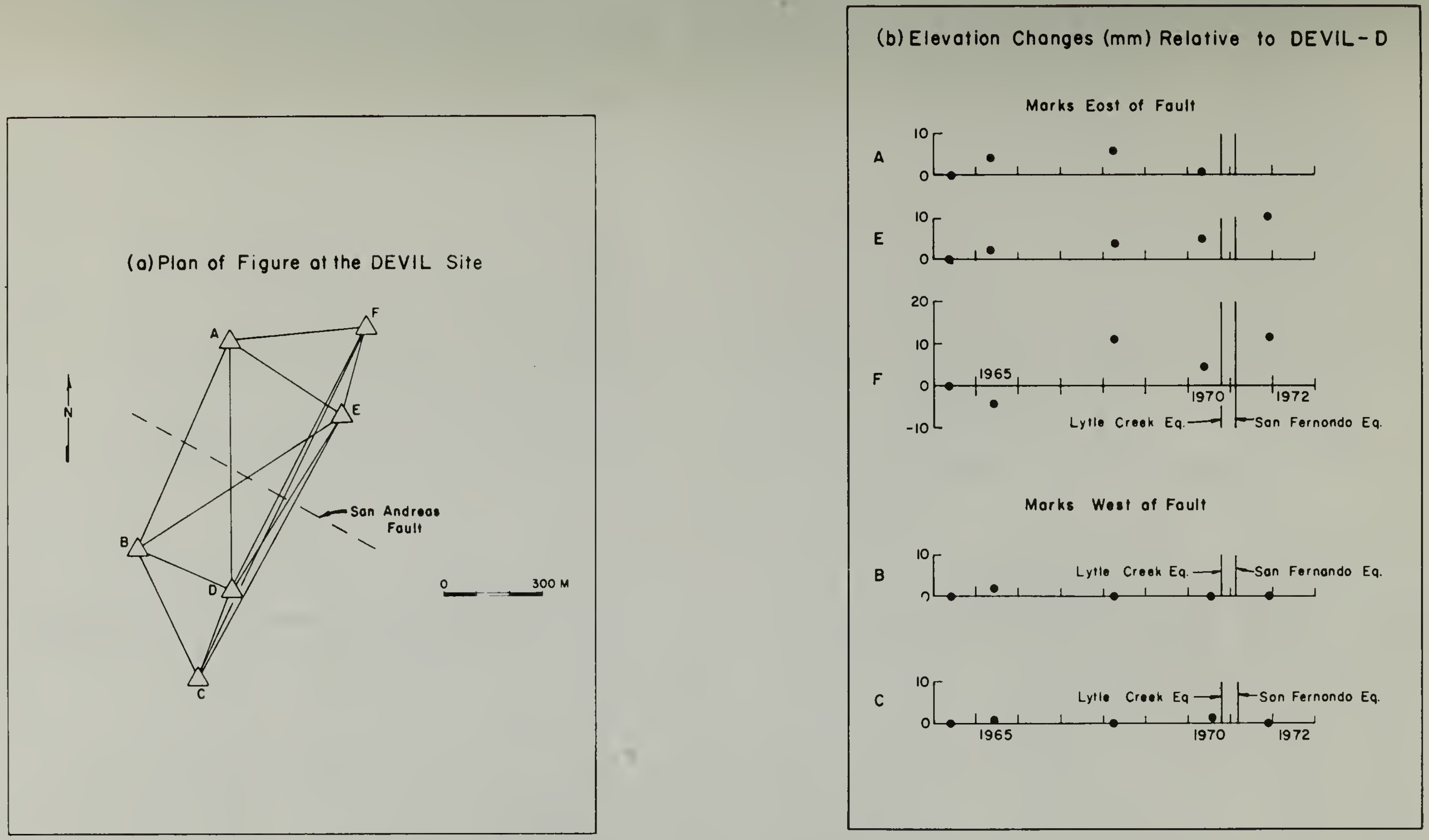
Small Survey Figures

DEVIL

The DEVIL site was established on the San Andreas fault in 1964 and resurveyed in 1965, 1966, 1968, 1970, and 1972 (figure 4a). Levels were run in 1964, 1965, 1968, 1970, and 1971. There were maximum changes of ± 4 seconds of arc in the astronomic azimuth of line B-D between the surveys; the taped length of B-D increased by 1 mm (0.039 in.) (figure 4b). The triangle closures and angle corrections were generally well within the accuracy specifications of the survey. The results of the horizontal surveys indicate no fault movement greater than the survey error prior to 1970 and about 15 mm (0.59 in.) of right-lateral movement between 1970 and 1972 (Miller, 1972). The vertical surveys indicate that the northeast side of the San Andreas fault is moving up relative to the southwest side.

RIALTO

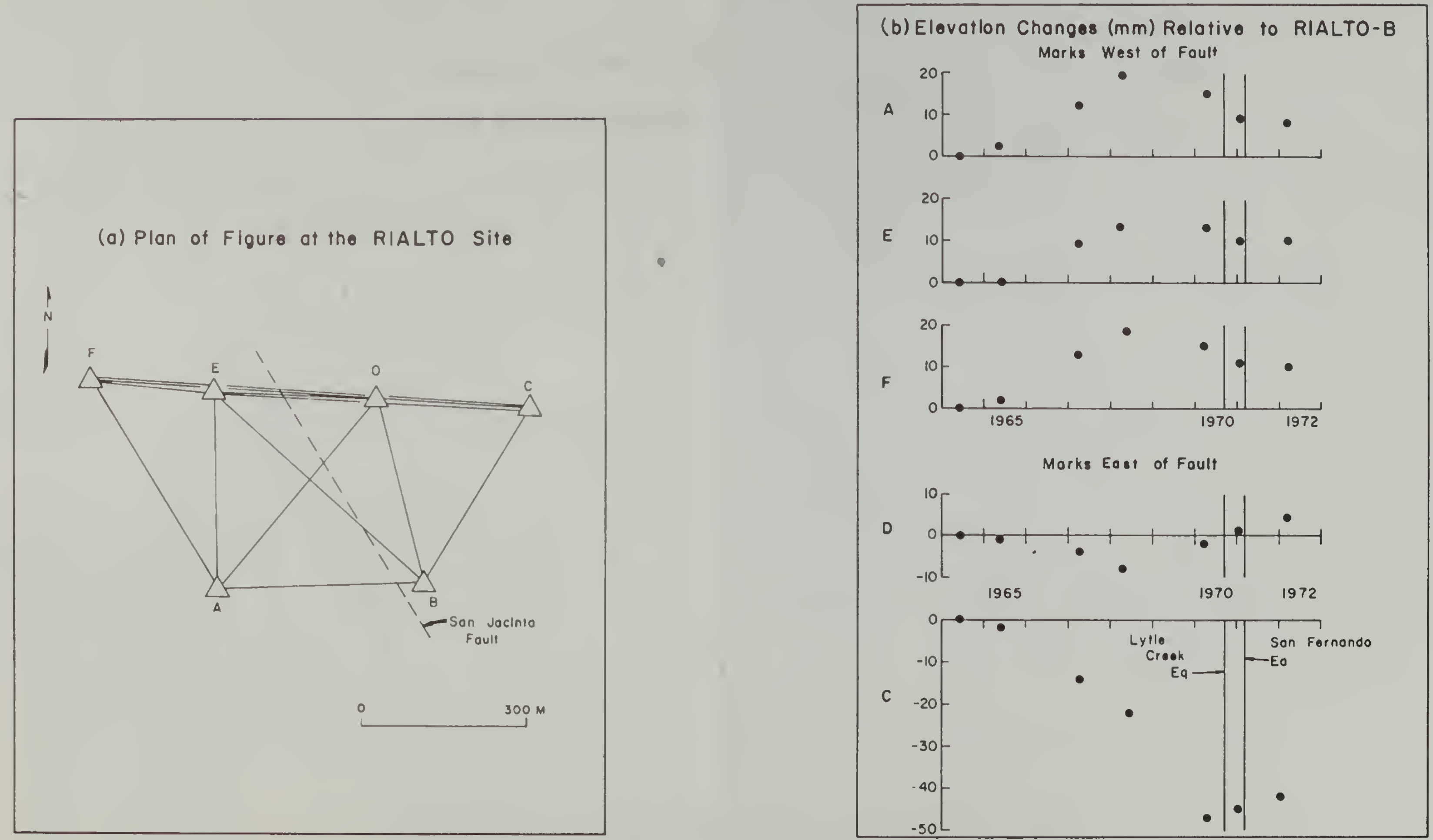
The RIALTO site was established in 1964 on the San Jacinto fault and reobserved in 1965, 1967, 1968, 1970, and 1972 (figure 5a). The astronomic azimuth of line B-D remained essentially constant until the survey of 1972; at that time it decreased about 3 seconds of arc. The taped length of line B-D varied over a range of 5 mm (figure 5b). Triangle closures and angle corrections were within the specifications of the surveys. There is reason to believe that mark C was disturbed by heavy equipment between 1968 and 1970 (Miller, 1972).



(a) Plan of the survey figure at the DEVIL site

(b) Elevation changes of each mark relative to DEVIL-D

Figure 4. DEVIL site on San Andreas fault.



(a) Plan of the survey figure at the RIALTO site

(b) Elevation changes of each mark relative to RIALTO-B.

Levels were run at RIALTO site in 1964, 1965, 67, 1968, 1970, 1971, and 1972. A level line con- cting RIALTO to COLT was established in 1971 and surveyed in 1972.

The results of the horizontal surveys showed a right- teral creep rate of about 2 mm per year until 1968. tween 1968 and 1970, there may have been some hall amount of fault movement, but the rate was not large as the pre-1968 rate. From 1970 to 1972 there as no fault movement larger than the survey error.

OLT

The COLT site was established on the San Jacinto ult in 1964 and resurveyed in 1965, 1967, 1969, 70, and 1972 (figure 6a). The astronomic azimuth of e B-D decreased about 15 seconds from 1964 to 72. The taped length of line B-D increased 3 mm tween 1964 and 1972. There is some indication that ark F was disturbed between 1970 and 1972, and lculated position vectors suggest that marks F and D ve been unstable since 1964 (Miller, 1972). Levels ere run at this site in 1964, 1965, 1967, 1968, 1969, 71, and 1972. A level line connecting this site to IALTO was established in 1971 and reobserved in 72.

The results of the horizontal surveys indicate that, tween 1964 and 1970, there was fault movement with rate of about 1.5 mm (0.059 in) per year on the San cinto fault. In 1972 all the marks moved southeast lative to mark A. The vertical surveys also indicate a bstantial change in 1970 (figure 6b).

Survey Results near San Bernardino

At DEVIL, there was no indication of fault move- ent prior to 1970 whereas, between 1970 and 1972, ere was 15 mm (0.59 in) of right-lateral movement at e site. At RIALTO, there was more or less steady ght-lateral movement of 2 mm per year (total about mm _ 0.39 in) between 1964 and 1968 with, erhaps, slight right-lateral movement between 1968 nd 1970. After 1970, there was essentially no move- ent. At COLT, there was movement with a rate of bout 1.5 mm (0.059 in) per year (total about 9 to 10 m = 0.35 to 0.39 in) between 1964 and 1970, and ere was no evidence of movement after 1970. The vel data at DEVIL show a more or less steady uplift f the northeastern block relative to the southwestern lock, but the data are too sparse to draw firm conclu- ons about possible changes in rates. At RIALTO, the vel data indicate a change in trend between the 1968 nd 1970 surveys (figure 5b) while at COLT a change trend occurs between the 1970 and 1972 surveys. hus, both horizontal and vertical data at COLT and EVIL suggest a major change in the strain field bet- een 1970 and 1972.

Geodimeter Data

Three geodimeter lines of the California eodimeter Network have been measured near this rea: lines 66, 67, and 70 (Greensfelder and Bennett, 1973; figure 7). Lines 66 and 67 show length increases of 4 to 5 cm (1.5-2 in) between 1968 and 1970, and they show length decreases of about 2 cm between 1970 and 1972. Line 70 lengthened by about 10 cm (3.9 in) between 1968 and 1972. Thus, the geodimeter data also suggest a change in the strain field between 1970 and 1972. If the hypothesis of periodic fluctuations in line lengths proposed by Greensfelder and Bennett (1973) is valid, the data from these small survey figures may be reflecting this change. More data are needed to resolve this problem.

On September 12, 1970, a magnitude 5.4 earthquake occurred about 15 miles (25 km) northwest of the San Bernardino area, and on February 9, 1971, the magnitude 6.4 San Fernando earthquake occurred 62 miles (100 km) to the west of the San Bernardino area. These two events are indicated on figures 4b, 5b, and 6b. It is possible that the change in the strain field between 1970 and 1972 was related to one or both of these two events, but the data are not adequate to resolve this question.

Kanamori and Chung (1973) and Wu and others (1973) found changes in seismic velocities in the vicinity of Riverside between 1966 and 1971 that might be related to future earthquake activity in the vicinity of Riverside. This suggests the possibility that the small survey figures may be providing information on dilatancy preceding an earthquake. Either more frequent measurements, or expansion of figures and level nets, should be made to test this possibility.

GROUND SHAKING SEVERITY

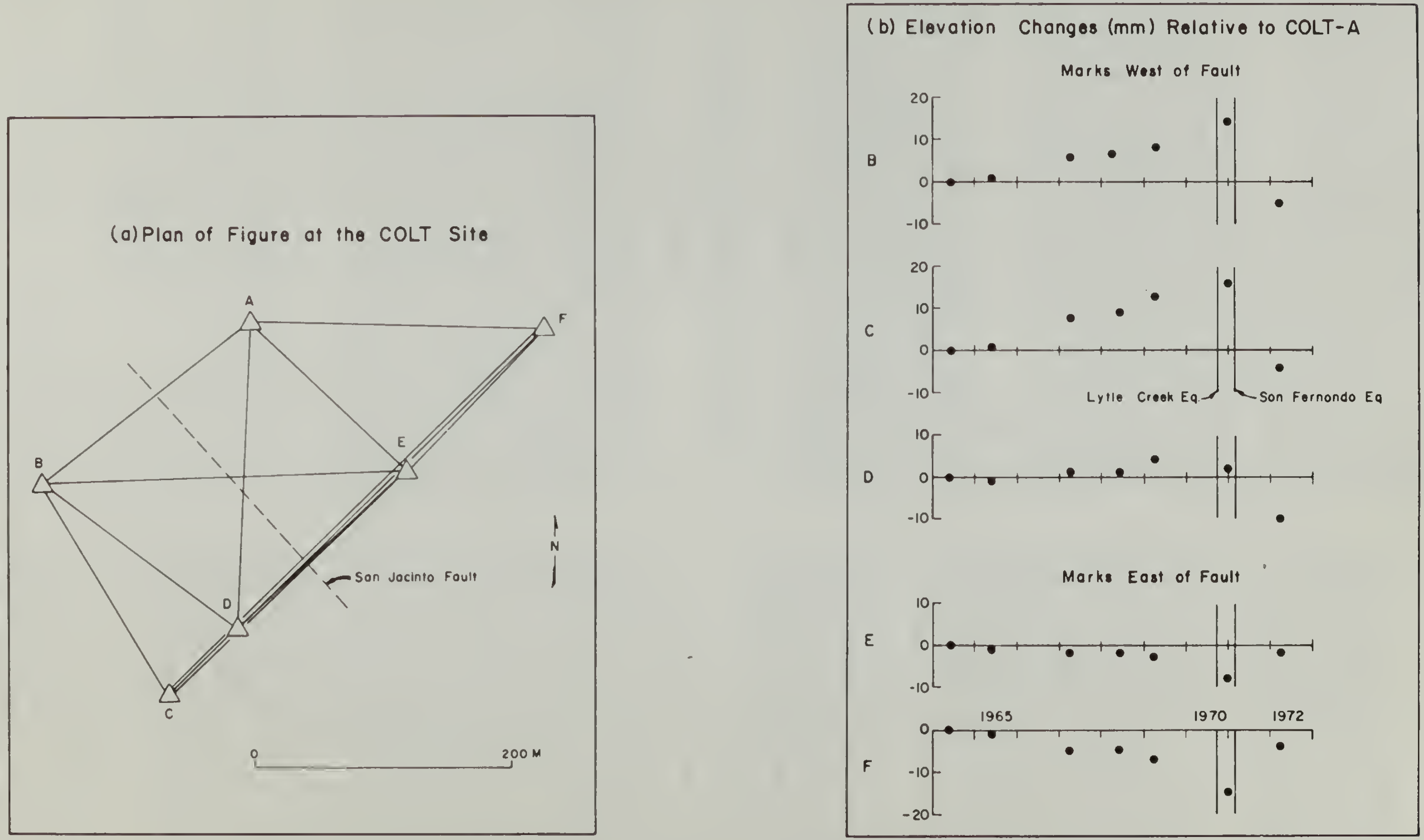
Accelerations

To estimate the accelerations in rock, Greensfelder (1974) determined the faults in the area which may be active in the future and assigned potential earthquake magnitudes to each. Rock accelerations at varying distances from the source faults were determined from the curves of Schnable and Seed (1973). The faults, estimated lengths of rupture, and estimated magnitudes used in this study are shown on table 2. Maximum credible earthquakes are the largest earthquakes that might occur on these faults, given our present knowledge of fault lengths and the tectonic and geologic environment of the area. The definition of maximum credible earthquake does not include a time factor.

It is probably not necessary to consider other maximum credible earthquakes that could affect the study

Table 2. Maximum credible earthquake and length of surface rupture in the vicinity of southwest San Bernardino County (from Greensfelder, 1974).

Fault	*Local magnitude*	*Length of rupture*
San Andreas	8.5	250 miles (400 km)
San Jacinto	7.5	56 miles (90 km)
Elsinore-Whittier(?)	7.5(?)	56?miles (90 km)
Cucamonga	6.5	10 miles (16 km)



(a) Plan of the survey figure at the COLT site

(b) Elevation changes of each mark relative to COLT-A.

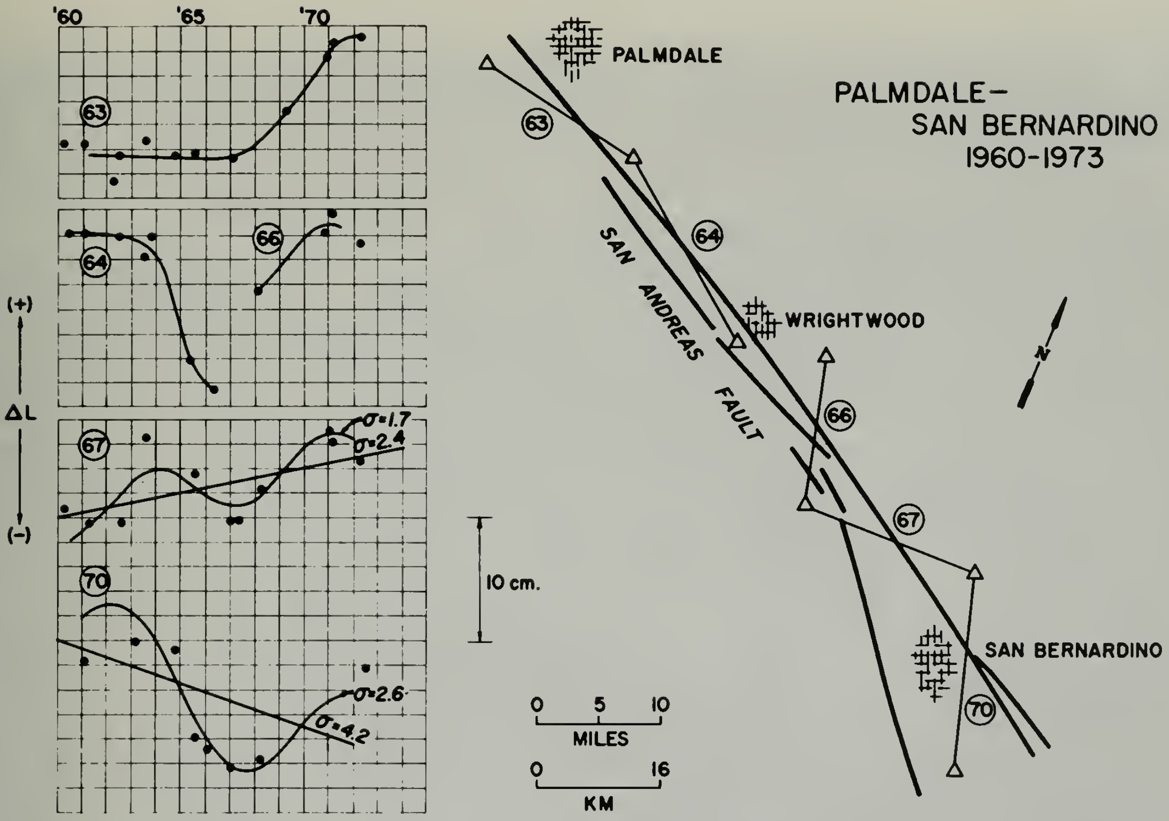


Figure 7. Geodimeter line length changes, 1960-72, in the vicinity of San Bernardino (Greensfelder and Bennett, 1973).

area, because the four events in table 2 bracket the area and provide a reasonable range of possible magnitudes.

The largest earthquake that could be expected to affect the study area would be a magnitude 8.5 event on the San Andreas fault. Plates 5A and 5B show the maxmum peak acceleration in bedrock which a magnitude 8.5 earthquake on the San Andreas fault would be expected to produce in the study area. Accelerations of over 0.5 g would be developed throughout most of the San Bernardino area. The sharp relief of the San Bernardino Mountains could have an unpredictable effect on the accelerations (possibly amplifying the accelerations greatly), and this should be taken into consideration when designing proposed structures (Davis and West, 1973).

Plates 5A and 5B show the maximum accelerations that would be produced in rock from a magnitude 7.5 earthquake on the San Jacinto fault. A magnitude 7.5 event on the San Jacinto fault would be larger than the previous events noted on the southern part of the fault (table 1). Even though the magnitude of the 1899 earthquake is unknown, it well may have been near 7, and a magnitude 7.5 earthquake on the northern San Jacinto fault is believed to be a reasonable estimate.

Most of the San Bernardino area would be subjected to accelerations over 0.5 g by a large earthquake on the San Jacinto fault; and, as discussed previously, the accelerations in the mountains could be much higher.

Plate 5A and 5B show the maximum peak acceleration that would be generated in rock due to a magnitude 6.5 earthquake on the Cucamonga fault. The western part of the fault trace (outside the county) was located approximately, but adequately, from Greensfelder's (1974) map. An earthquake of this size on the Cucamonga fault is not unreasonble, because a stress field similar to that preceding the 1971 San Fernando earthquake seems to be affecting the area (Rodgers and Chinnery, 1973). Accelerations over 0.5 g would be generally confined to the area within about 6.2 miles (10 km) of the fault trace. Attenuation would reduce rock accelerations at greater distance from the causative fault. Accelerations in the mountains could be much higher than shown on plates 5A and 5B.

Plates 5A also shows the maximum peak acceleration that would be generated in rock from a magnitude 7.5 earthquake on the Elsinore-Whittier fault. The location of the fault is approximate (Durham and Yerkes, 1964). Accelerations well over 0.5 g would be expected in the vicinity of Prado Flood Control Dam. Accelerations in the eastern half of the study area are not shown since they are generally less than 0.3 g.

The accelerations shown on plate 5A and 5B would be measured on rock, but not necessarily crystalline bedrock. For purposes of this report, rock is defined as material with a shear-wave velocity greater than about 2000 feet (600 m) per second (Greensfelder, 1974). The alluvial fill in the valleys exhibits shear-wave velocities of 2000 feet (600 m) per second and greater at depths of 500 feet (150 m) and below. Thus, for the purpose of calculating the response of the ground surface, these rock accelerations should be used as input for localities where the depth of alluvium is greater

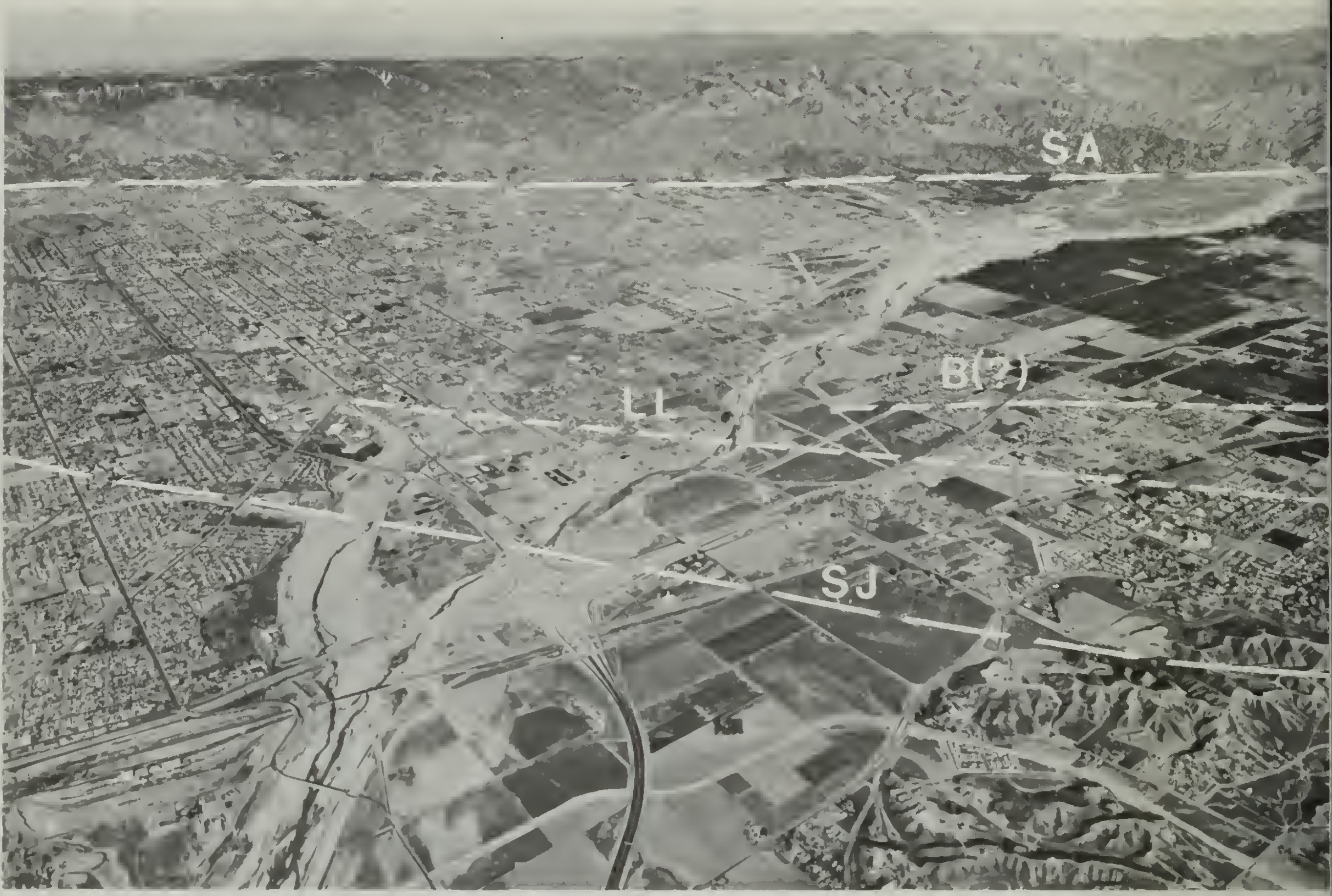


Photo 21 San Andreas fault zone (SA) on the east and San Jacinto fault zone (SJ) on the west bound central San Bernardino; view northeast. The Loma Linda fault (LL) and the questionable extension of the Banning fault (B?) lie between the two major faults. The thickness of alluvium exceeds 1200 feet in the center of the area northeast of the San Jacinto fault. In the late 1800s, most of the valley region northeast of the San Jacinto was an area of springs and marshland with flowing streams. Mining of ground water in the first half of this century caused at least 1 foot of subsidence between Loma Linda (center of photo) and San Bernardino (left). However, the lowering of the groundwater level has greatly reduced the potential for liquefaction. Photo by Gordon Davis, Aerial Enterprises, San Bernardino.

than 500 feet (150 m). Where the alluvium is less than 500 feet (150 m) thick, the effect of the alluvium on the acceleration should be recalculated.

The locations of the contours shown in plates 5A and 5B were determined from observational data, and some of the acceleration-distance curves were derived from data several tens of kilometers from the source faults. Because of this, the distance of some of the contour locations from the causative fault could be in by as much as 15 to 25 percent. The acceleration values also could be in error by as much as 10 to 15 percent. Therefore, detailed conclusions should not be drawn from these maps. In general terms, the maps depict the relative variation of the accelerations with distance from a fault.

Ground Surface Response

Since most structures are built on the ground surface, we are naturally more interested in the behavior of the surface than we are in the behavior of material 500 feet (150 m) below the surface. Several methods exist for the calculation of surface response given an input motion (Seed and others, 1970; Murphy and others, 1971; Schnable and others, 1972). Whatever calculation method is used, it can generally be assumed that: (a) the higher frequency seismic waves are relatively more attenuated by alluvium than the lower frequency waves; (b) the deeper the soil deposits are, the more their shaking behavior corresponds to the lower frequencies of any seismic event; and (c) large-amplitude motions are more attenuated when nonelastic effects are included in the equations used to calculate the ground response than when purely elastic effects are used in equations to calculate ground response.

As a general conclusion for the study area, it may be assumed that the areas of deeper alluvium should receive more analysis prior to design and construction of significant structures than the areas of shallower alluvium. Plates 1 and 4 can be used together with plate 5 and generalized soil columns to determine general areas of relative hazard for different types of structures, using the methods devised by Seed and others (1970). These data can also be used as the initial input for a detailed investigation of a building site. However, the data shown on the plates cannot be used in place of detailed site studies.

Factors used in design of structures include the aceleration and velocity response spectra of the ground urface. The maximum peak acceleration is used to cale any acceleration record. The scaled record is then nodified mathematically to determine the effect that he soil column beneath the structure has on the aceleration record.

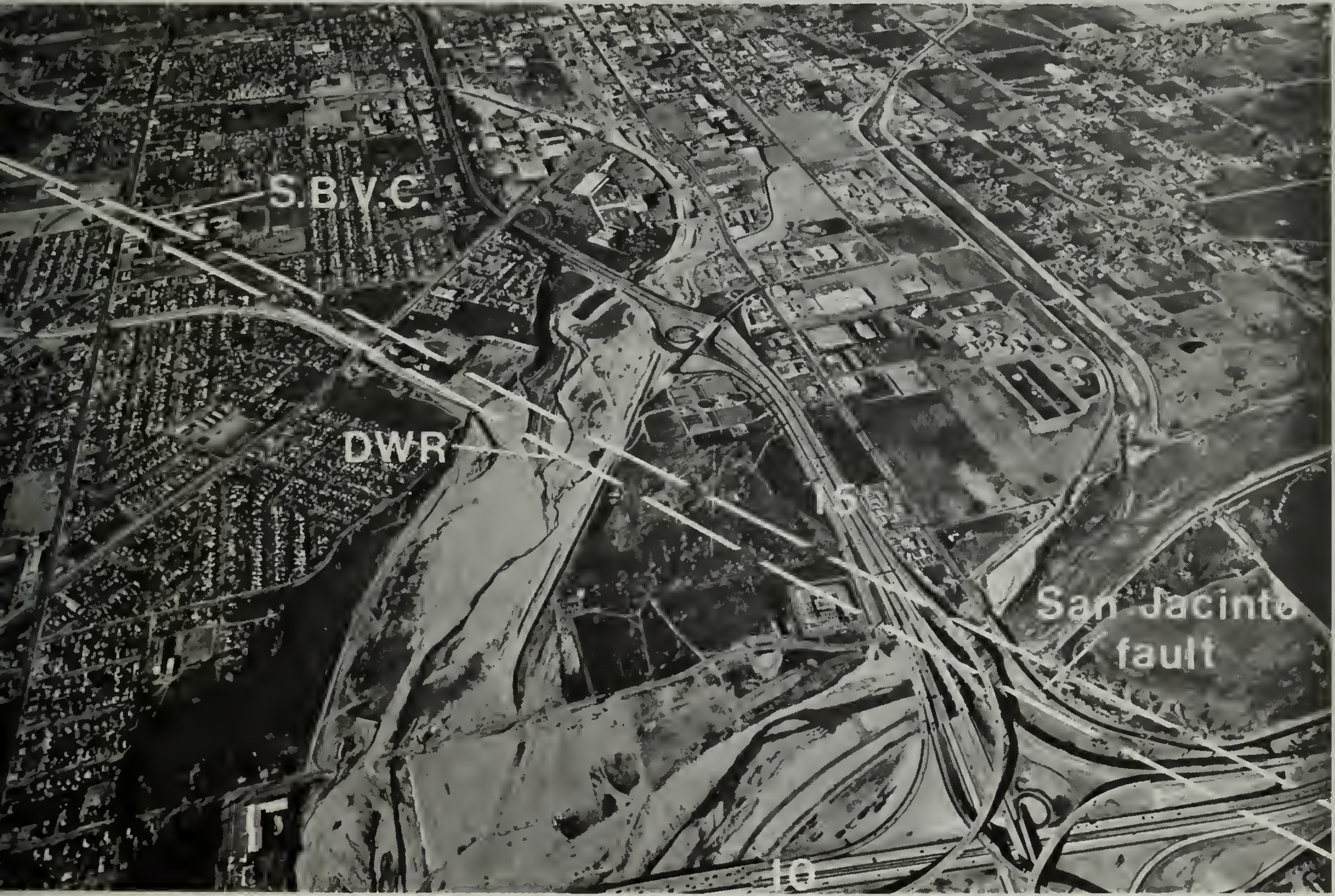
A useful tool in designing structures on locations in eismically active areas, such as the San Bernardino rea, is the ground response map. These maps present losely spaced observational and mathematical seismic letail and provide relatively detailed information on he behavior of a given site during a seismic event in erms useful to design engineers. The preparation of round response maps was outside the scope of this proect. This report does include maps showing maximum eak acceleration and alluvial thickness, which could e used in the preparation of ground response maps.

LIQUEFACTION POTENTIAL

Liquefaction is the transformation of cohesionless oils from a solid state to a liquid state due to increased pore-water pressures (Youd and others, 1973). When a saturated sandy or silty soil is subjected to seismic shaking, this often causes the pore pressure of the soil to increase enough to liquefy the soil.

Three types of ground failure are generally associated with liquefaction (Youd and others, 1973): (1) Flow landslides occur on moderate to steeply dipping slopes, and these slides can often cause damage downslope from the area of liquefaction. (2) Lateral-spreading landslides occur on gently dipping to nearly horizontal slopes, but they do not generally move as far as flow landslides. However, these slides can be reactivated by repeated shaking. (3) Quick-condition failure can occur on horizontal, saturated sandy or silty soils, where drainage is generally confined to the immediate area of liquefaction. In areas where liquefaction has occurred, buildings and cars often settle into the ground, the lighter underground structures, such as gasoline storage tanks and septic tanks, often float to the surface.

The potential for liquefaction exists in all the alluvial portions of the study area. The soils are generally sandy and/or silty throughout the area; and,



hoto 22. San Jacinto fault zone, through south San Bernardino and Colton; view northward. The San Jacinto fault bisects the campus of an Bernardino Valley College (S.B.V.C.), follows the east branch of the California Aqueduct pipeline (DWR) near the junction of Lytle reek flood control channel and Warm Creek (left center), and passes through the northeast quadrant of the Interstate 10 and 15 inerchange (lower right). Photo by Gordon Davis, Aerial Enterprises, San Bernardino.

where these soils are saturated, liquefaction is possible. The saturated condition occurs wherever the water table is less than 50 feet (15 m) deep or whenever there is heavy rainfall. The liquefaction potential is generally lower during seasons when the water table is deeper than 50 feet and is generally higher during seasons when the water table is shallower than 50 feet. However, there are some areas, such as parks with ponds or heavily irrigated lawns, where a perched shallow water-bearing zone makes liquefaction possible at all times.

Liquefaction potential in the study area should be estimated in detail, assuming a very shallow water table everywhere, using the methods devised by Seed an Idriss (1971) and Youd and others (1973). This woul require collecting all available shallow boring dat estimating the physical properties of the soils, and computing the liquefaction potential for each of the fou maximum credible earthquakes discussed earlier. Th information would assist in distinguishing local vari tions in liquefaction potential and allow generalize zoning regulations to be established; it would also hel to identify an area where liquefaction-caused lan slides might do damage downslope. A careful evalu tion of the liquefaction potential should be require before approving building sites for major constructio projects and housing developments.

REFERENCES

Bailey, T.L., and Jahns, R.H., 1954, Geology of the Transverse Range province, southern California, *in* Jahns, R.H., editor, Geology of southern California: California Division of Mines Bulletin 170, chapter 2, p. 83-106, plate 4 (map scale 1:375,000).

Baird, A.K., Morton, D.M., Woodford, A.O., and Baird, K.W., 1974, Transverse Ranges province: A unique structural-petrochemical belt across the San Andreas fault system: Geological Society of America Bulletin, v. 85, no. 2, p. 163-174, 9 figures.

Barbat, W.F., 1958, Los Angeles basin area, California, *in* Higgins, J.W., editor, A guide to the geology and oil fields of the Los Angeles and Ventura regions: Pacific Section, American Association of Petroleum Geologists, p. 37-49.

Burnham, W.L., 1973, U.S. Geological Survey, Menlo Park, California, personal communication.

California Department of Water Resources, 1966, Upper Santa Ana River drainage area: California Department of Water Resources Land and Water Use Survey Bulletin 71-64.

California Department of Water Resources, 1970a, Meeting water demands in the Chino-Riverside area—Appendix A, Water supply: California Department of Water Resources Bulletin 104-3, 108 p., 20 plates.

California Department of Water Resources, 1970b, Meeting water demands in the Bunker Hill-San Timoteo area: California Department of Water Resources Bulletin 104-5, 75 p.

Coffman, J.L., and von Hake, C.A., editors, 1973, Earthquake history of the United States [revised edition (through 1970)]: U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Crowell, J.C., 1962, Displacement along the San Andreas fault, California: Geological Society of America Special Paper 71, 61 p.

Davis, L.L., and West, L.R., 1973, Observed effects of topography on ground motion: Seismological Society of America Bulletin, v. 63, no. 1, p. 283-298.

Durham, D.L., and Yerkes, R.F., 1964, Geology and oil resources of the eastern Puente Hills area, southern California: U.S. Geological Survey Professional Paper 420-B, plate 1 (map scale 1:24,000).

Dutcher, L.C., and Garrett, A.A., 1963, Geologic and hydrolog features of the San Bernardino area, California—with speci reference to underflow across the San Jacinto fault: U. Geological Survey Water Supply Paper 1419, 114 p., plate (map scale 1:31,680).

Eckis, Rollin, 1934, South coastal basin investigation; geolo and ground water storage capacity of valley fill: Californ Division of Water Resources Bulletin 45, 279 p., plates A,B,

Engel, Rene, 1959, Geology of the Lake Elsinore quadrangl California: California Division of Mines Bulletin 146, p. 1-58.

Fett, J.D., Hamilton, D.H., and Fleming, F.A., 1967, Continuing su face displacements along the Casa Loma and San Jacin faults in San Jacinto Valley, Riverside County, Californi Engineering Geology, v. 4, no. 1, p. 22-32.

Fife, D.L., 1968, Pyramid reservoir slope stability, State Wat Facilities, California Aqueduct, West Branch Division, L Angeles County, California: Office Report, California Depa ment of Water Resources, Sacramento California, 18 p., plates (map scale 1″= 400′).

Garrett, A.A., and Thomasson, H.G. Jr., 1949, Ground water ou flow from the Chino basin, California, and the controlli geologic and hydrologic conditions: U.S. Geological Surv Open-File Report, plate 102 (map scale 1:62,500).

Gray, C.H. Jr., 1961, Geology of the Corona South quadrangle a the Santa Ana Narrows area, Riverside, Orange, and San Be nardino Counties, California: California Division of Min Bulletin 178, 120 p., plates 1 and 3 (map scale 1:24,000).

Greensfelder, R.W., 1974, Maximum credible rock accelerati from earthquakes in California: California Division of Min and Geology Map Sheet 23 (map scale 1:2,500,000).

Greensfelder, R.W., and Bennett, J.H., 1973, Characteristics strain variation along the San Andreas fault from geodimet measurements, *in* Kovach, R.L., and Nur, Amos, editors, Pr ceedings of the conference on tectonic problems of the S Andreas fault system: Stanford University Publication Geological Sciences, v. XIII, p. 54-63.

Hadley, David, 1973, Microearthquake distribution and mecha isms of faulting in the Fontana-San Bernardino area southern California: Unpublished M.A. thesis, University California, Riverside, California.

lall, W.H., 1888, Detailed irrigation map of San Bernardino: California Engineering Department Report to the Legislature.

lileman, J.A., Allen, C.R., and Nordquist, J.M., 1974, Seismicity of the southern California region 1 January 1932 to 31 December 1972: California Institute of Technology Seismological Laboratory, Pasadena, California, 404 p.

ahns, R.H., 1954a, Geologic guide for the northern part of the Peninsular Range province, southern California, *in* Jahns, R.H., editor, Geology of southern California: California Division of Mines Bulletin 170, Geologic Guide No. 5, 59 p., maps 1-7 (scale 1:96,000), maps 8 and 10 (scale 1:203,000).

ahns, R.H., 1954b, Geology of the Peninsular Range province, southern California and Baja California, *in* Jahns, R.H., editor, Geology of southern California: California Division of Mines Bulletin 170, chapter 2, p. 29-52.

ennings, C.W., 1973, Preliminary fault and geologic map: California Division of Mines and Geology Preliminary Report 13 (map scale 1:750,000).

achadoorian, R., 1971, An estimate of the damage, *in* The San Fernando, California, earthquake of February 9, 1971: U.S. Geological Survey Professional Paper 733, p. 5.

anamori, H., and Chung, W.Y., 1973, Temporal changes in P-wave velocity in southern Californnia [abstract]: EOS—American Geophysical Union Transactions, v. 54, no. 11, p. 1135.

avarty, F.B., 1973, Ground water contour map Bunker Hill-San Timoteo Basin, Fall 1972: San Bernardino Municipal Water District unpublished map.

awson, A.C., and others, 1908, The California earthquake of April 18, 1906; Report of the State Earthquake Investigation Commission: Carnegie Institution of Washington Publication 87, 191 p. and atlas.

ofgren, B.E., 1965, Subsidence related to ground water withdrawal, *in* Landslides and subsidence geologic hazards conference: The Resources Agency of California, p. 105-110.

ofgren, B.E., 1971, Estimated subsidence in the Chino-Riverside-Bunker Hill-Yucaipa areas in southern California for a postulated water level lowering, 1965-2015: U.S. Geological Survey Open-File Report, Water Resources Division, Sacramento, California.

lendenhall, W.C., 1905, The hydrology of San Bernardino Valley, California: U.S. Geological Survey Water-Supply Paper 142, 124 p.

lendenhall, W.C., 1908, Ground waters and irrigation enterprises in the foothill belt, southern California: U.S. Geological Survey Water-Supply Paper 219, p. 39-42, plates III and V.

liller, R.E., and Singer, J.A., 1971, Subsidence in the Bunker Hill-San Timoteo area, southern California: U.S. Geological Survey Open-File Report, 28 p.

liller, R.W., 1972, Results of triangulation for earth movement study at California Aqueduct-fault crossing sites; section 1, supplement 9: U.S. Department of Commerce, National Ocean Survey.

lorton, D.M., 1974, U.S. Geological Survey, Menlo Park, California, personal communication.

Murphy, J.R., Davis, A.H., and Weaver, N.L., 1971, Amplification of seismic body waves by low-velocity surface layers: Seismological Society of America Bulletin, v. 61, no. 1, p. 109-146.

Oakeshott, G.B., editor, 1975, San Fernando, California, earthquake of 9 February 1971: California Division of Mines and Geology Bulletin 196, 463 p.

Phillips, E.H., 1971a, Geologic structure, *in* Meeting water demands in the Bunker Hill-San Timoteo area; geology, hydrology, and operation—economic studies: California Department of Water Resources, Memorandum Report, Southern District, p. 27-38.

Phillips, E.H., 1971b, Lines of equal elevation of the effective base of the ground water reservoir, *in* Meeting water demands in the Bunker Hill-San Timoteo area: geology, hydrology, and operation—economic studies: California Department of Water Resources, Memorandum Report, Southern District, p. 51-59.

Poland, J.F., and Davis, G.H., 1969, Land subsidence due to withdrawal of fluids, *in* Varnes, D.J., and Kiersch, George, editors, Reviews in engineering geology: Geological Society of America, v. 2, p. 187-270.

Rodgers, D.A., and Chinnery, M.A., 1973, Stress accumulation in the Transverse Ranges, southern California, *in* Kovach, R.L., and Nur, Amos, editors, Proceedings of the conference on tectonic problems of the San Andreas fault system: Stanford University Publications, Geological Sciences, v. XIII, p. 70-79.

Rowe, Larry, 1973, San Bernardino Municipal Water District, personal communication.

Schnable, P.H., Seed, H.B., and Lysmer, J., 1972, Modification of seismograph records from effects of local soil conditions: Seismological Society of America Bulletin, v. 62, no. 6, p. 1649-1664.

Schnable, P.H., and Seed, H.B., 1973, Acceleration in rock for earthquakes in the western United States: Seismological Society of America Bulletin, v. 63, no. 2, p. 501-516.

Scott, N.H., 1971, Preliminary report on felt area and intensity, *in* The San Fernando, California, earthquake of February 9, 1971: U.S. Geological Survey Professional Paper 733, p. 153-154.

Seed, H.B., Idriss, I.M., and Dezfulian, Houshang, 1970, Relationships between soil conditions and building damage in the Caracas earthquake of July 29, 1967: Earthquake Engineering Research Center Report 70-2, February 1970, University of California, Berkeley, California.

Seed, H.B., and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundation Division, American Society of Civil Engineers, v. 97, no. SM9, p. 1249-1273.

Sharp, R.V., 1967, Geology of the San Jacinto fault zone in the Peninsular Ranges of southern California: Geological Society of America Bulletin, v. 78, no. 6, p. 705-730, map scale 1:62,500.

Sidler, W.A., 1973, The great flood of January 22, 1862: San Bernardino County Museum Association Quarterly, v. XXI, nos. 1 and 2, p. 6-20.

Townley, S.D., and Allen, M.W., 1939, Descriptive catalog of earthquakes of the Pacific Coast of the United States: Seismological Society of America Bulletin, v. 29, no. 1, p. 1-252.

Wallace, R.E., 1968, Notes on stream channels offset by the San Andreas fault, southern Coast Ranges, California, *in* Dickinson, W.R., and Grantz, Arthur, editors, Proceedings of conference on geologic problems of the San Andreas fault system: Stanford University Publications, Geological Sciences, v. XI, p. 6-21.

Weber, F.H. Jr., 1974, Elsinore fault study: California Division of Mines and Geology report in preparation.

Willingham, C.R., 1968, A gravity survey of the San Bernardino Valley, southern California: Unpublished M.A. thesis, University of California, Riverside.

Wood, H.O., 1955, The 1857 earthquake in California: Seismological Society of America Bulletin, v. 45, p. 47.

Woodford, A.O., Shelton, J.S., and Moran, T.G., 1944, Geology and soil possibilities of the San Jose Hills, California: U.S. Geological Survey Oil and Gas Investigation Preliminary Map 23 (map scale 1:62,500).

Woodward-Lundgren and Associates, 1973a, Geologic, seismic and active fault investigation, part A; Proposed Veterans Administration Hospital, site no. 4, Loma Linda, California (dated January 5, 1973): Unpublished report to Veterans Administration, Washington, D.C.

Woodward-Lundgren and Associates, 1973b, Preliminary soi
vestigation and site response analyses for the Prop
Veterans Administration Hospital, site no. 4, Loma Li
California (dated January 8, 1973): Unpublished repor
Veterans Administration, Washington, D.C.

Woodward-Lundgren and Associates, 1973c, Supplem
studies and recommendations, Proposed Veterans Admini
tion Hospital, Loma Linda, California (dated July 6, 1973):
published report to Veterans Administration, Washington,

Wu, A.P., Kanamori, H., and Alewine, R.W. III, 1973, Tem
changes in Rayleigh-wave phase-velocity in southern Ca
nia [abstract]: EOS—American Geophysical Union Tran
tions, v. 54, no. 11, p. 1135.

Youd, T.L., Nichols, D.R., Helley, E.J., and Lajoie, K.R., 197
quefaction potential of unconsolidated sediments in
southern San Francisco Bay region, California: U.S. Geo
cal Survey Open-File Report.

Ziony, J.I., Wentworth, C.M., Buchanan-Banks, J.M., and Wa
H.C., 1974, Preliminary map showing recency of faultin
coastal southern California: U.S. Geological Su
Miscellaneous Field Studies Map MF-585, map scale 1:500

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THE RESOURCES AGENCY
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PREPARED IN COOPERATION WITH THE
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SPECIAL REPORT 113
"A" series, PLATE 8A

EXPLANATION

SURFICIAL DEPOSITS

Qaf

Artificial fill

Major occurrences of man-placed fill, both compacted and uncompacted. Includes major highway and sanitary fills, quarry refuse, and slag.

Qar

Active river channel alluvium

Unconsolidated alluvium of major drainage channels subject to, or recently subject to streamflood, especially near mountains and where not controlled by flood control measures. Many of the channels are subject to course shifting during periods of streamflood. Alluvium devoid, or nearly devoid of vegetation. Ranges from coarse bouldery alluvium near mountains to sandy alluvium in valley areas removed from mountains.

Qosa

Santa Ana River channel alluvium

Unconsolidated sandy alluvium of the Santa Ana River channel. Apparently not as recently subject to fluvial reworking as the adjacent Qar.

Qf

Alluvial fan deposits

Unconsolidated deposits of young coarse alluvium, radiating from mountain fronts. Alluvium ranges from coarse bouldery alluvium near mountain front to pebbly and cobbly alluvium where it grades into undifferentiated younger alluvium.

Qal

Younger alluvium undifferentiated

Unconsolidated alluvium of the valley area and along some major drainage courses within the highlands surrounding the valley.

Qc

Colluvium and talus

Major occurrences of unconsolidated coarse rocky colluvium and talus.

Qws

Wind blown sand areas

Major areas subject to active blowing sand which include some small sand dunes and other thin concentrations of wind blown sand. Arrows (←) indicate predominate direction of sand transport.

Qls
Qlso

Landslide

Qls = major landslides; includes landslide and scarp area where mappable. Landslide deposits consist of unconsolidated highly fragmented rock. Smaller landslides are outlined and indicated by arrows (←) without Qls symbol. Questionable landslides are queried. Arrows indicate principal direction of landslide movement.
Qlso = older highly dissected landslide deposits.

Qds

Dune sand

Major deposits of unconsolidated dune sand. Most deposits are stabilized with a vegetation cover. Locally reactivated where vegetative cover has been removed or destroyed.

Qoa

Older alluvium undifferentiated

Deposits of older alluvium which range from unconsolidated older alluvial fan deposits (fanglomerate) to indurated older decomposed clay-rich alluvium.

Holocene
Pleistocene
QUATERNARY

SEDIMENTARY ROCKS

Tst

San Timoteo Beds

Mostly gray to reddish, poorly bedded, unconsolidated to lithified nonmarine conglomeratic and sandy sediment.

Tcg

Conglomerate and sandstone

Late Tertiary (?) nonmarine sediments within the Cucamonga and San Andreas fault zones. Unconsolidated gray conglomerate in the eastern part of the Cucamonga fault zone. Consolidated cream, tan, and maroon sandstone and conglomerate in the San Andreas fault zone west of Waterman Canyon.

Tpss

Potato Sandstone (Mill Creek Formation of Gibson, 1971)

Predominantly gray, lithified nonmarine sandstone and conglomerate with minor limestone.

Pliocene

Tp	Tpsc
	Tpy
	Tps

Puente Formation

Tp = Puente Formation undifferentiated. Gray to brown marine siltstone, sandstone, and conglomerate.
Tpsc = Sycamore Canyon Member. Predominantly gray- to light-brown and white marine sandstone with local pebbly to bouldery sandstone conglomerate and siltstone.
Tpy = Yorba Member. Thin bedded white to brownish marine siltstone with lesser amounts of fine grained sandstone.
Tps = Soquel Member. Predominantly gray to light brown massive to well bedded marine sandstone with minor conglomerate and conglomeratic sandstone.

Tt

Topanga Formation

Predominantly white to light brown marine sandstone with lenses of conglomerate and conglomeratic sandstone.

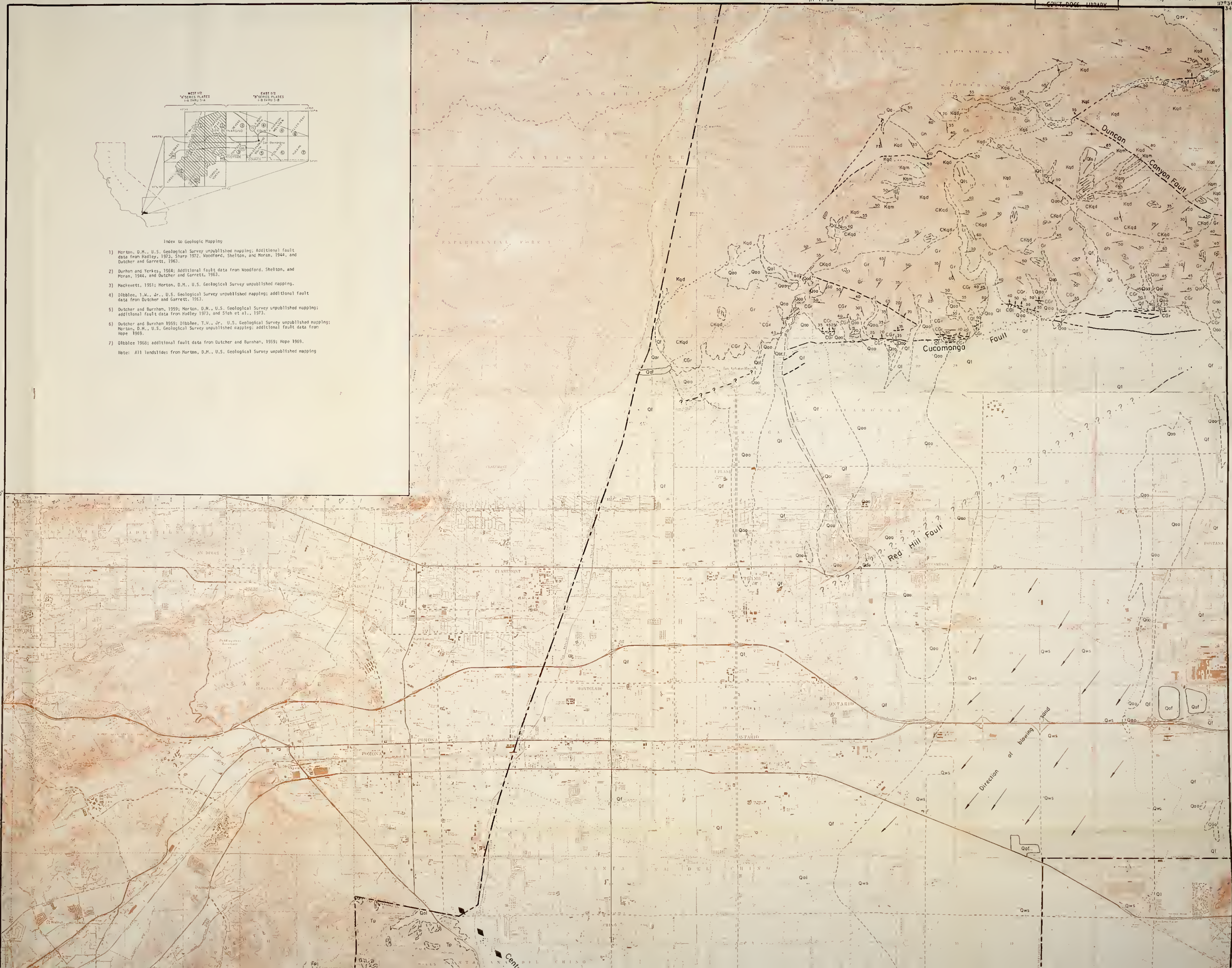
Miocene

Tvs

Vaqueros and Sespe Formations undifferentiated

Reddish-brown marine and nonmarine (?) sandstone

Eocene to Miocene
TERTIARY
CENOZOIC



Index to Geologic Mapping

1) Morton, D.M., U.S. Geological Survey unpublished mapping; Additional fault data from Hadley, 1973, Sharp 1972, Woodford, Shelton, and Moran, 1944, and Dutcher and Garrett, 1963.

2) Durham and Yerkes, 1964; Additional fault data from Woodford, Shelton, and Moran, 1944, and Dutcher and Garrett, 1963.

3) Mackevett, 1951; Morton, D.M., U.S. Geological Survey unpublished mapping.

4) Dibblee, T.W., Jr., U.S. Geological Survey unpublished mapping; additional fault data from Dutcher and Garrett, 1963.

5) Dutcher and Burnham, 1959; Morton, D.M., U.S. Geological Survey unpublished mapping; additional fault data from Hadley 1973, and Sieh et al., 1973.

6) Dutcher and Burnham 1959; Dibblee, T.W., Jr. U.S. Geological Survey unpublished mapping; Morton, D.M., U.S. Geological Survey unpublished mapping; additional fault data from Hope 1969.

7) Dibblee 1968; additional fault data from Dutcher and Burnham, 1959; Hope 1969.

Note: All landslides from Morton, D.M., U.S. Geological Survey unpublished mapping

Conglomerate and sandstone

Late Tertiary (?) nonmarine sediments within the Cucamonga and San Andreas fault zones. Unconsolidated gray conglomerate in the eastern part of the Cucamonga fault zone. Consolidated cream, tan, and maroon sandstone and conglomerate in the San Andreas fault zone west of Waterman Canyon.

Tpss

Potato Sandstone (Mill Creek Formation of Gibson, 1971)

Predominantly gray, lithified nonmarine sandstone and conglomerate with minor limestone.

TERTIARY

Tp | Tpsc | Tpy | Tps

Puente Formation

Tp = Puente Formation undifferentiated. Gray to brown marine siltstone, sandstone, and conglomerate.
Tpsc = Sycamore Canyon Member. Predominantly gray- to light-brown and white marine sandstone with local pebbly to bouldery sandstone conglomerate and siltstone.
Tpy = Yorba Member. Thin bedded white to brownish marine siltstone with lesser amounts of fine grained sandstone.
Tps = Soquel Member. Predominantly gray to light brown massive to well bedded marine sandstone with minor conglomerate and conglomeratic sandstone.

Tt

Topanga Formation

Predominantly white to light brown marine sandstone with lenses of conglomerate and conglomeratic sandstone

Miocene

Tvs

Vaqueros and Sespe Formations undifferentiated

Reddish-brown marine and nonmarine (?) sandstone

Eocene to Miocene

PLUTONIC ROCKS

Td

Diabase

Diabase body intruding Miocene quartz monzonite. Black fine to coarse-grained diabase.

Tqm

Miocene quartz monzonite

Whitish medium grained massive biotite quartz monzonite and granodiorite. Intrudes Pelona Schist.

Miocene

Kqm | CKqm

Cretaceous quartz monzonite

Kqm = gray medium to coarse-grained, massive to foliated quartz monzonite and granodiorite. Includes minor amounts of quartz diorite and gneiss.
CKqm = rock that has been cataclastically deformed.

Kqd | CKqd

Quartz diorite

Kqd = gray, medium to coarse-grained generally foliated biotite-hornblende quartz diorite. Includes minor amounts of quartz granodiorite and gneiss
CKqd = rock that has been cataclastically deformed.

CRETACEOUS

MESOZOIC

METAMORPHIC ROCKS

Ps

Pelona Schist

Gray to dark green, well to poorly foliated fine grained schist and quartzite. Commonly well layered. Intruded by the Miocene quartz monzonite unit; generally considered either Mesozoic or Precambrian in age.

Gn | Gnm | CGn

Gneiss and schist

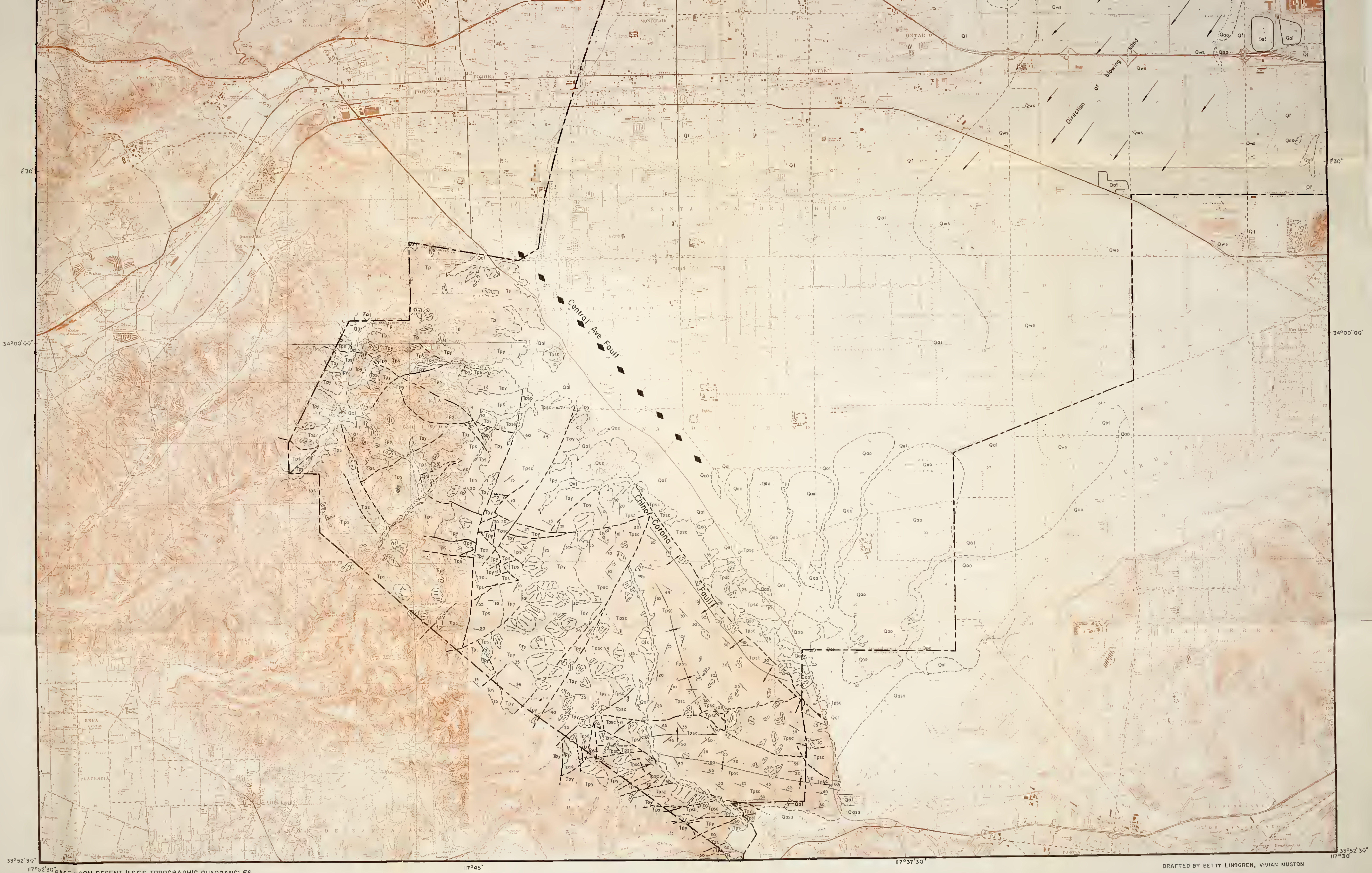
Gn = highly varied mixture of dark colored, poor to well layered, poorly to well foliated gneiss and schist; generally biotite bearing. Structurally complicated. Locally abundant marble layers.
Gnm = largest marble layers.
CGn = rock that has been cataclastically deformed. Pre-Cretaceous, generally considered Precambrian in age.

Gr | CGr

Granulitic Rock

Gr = highly varied mixture of extremely deformed layered, metamorphic rock characterized by presence of pyroxene and hornblende. Locally abundant marble layers and local quartzite and amphibolite.
CGr = rock that has been cataclastically deformed. Pre-Cretaceous, generally considered Precambrian in age.

Note: Where area is underlain by undifferentiated mixture of two map units composite symbol is used (e.g. Qal and Qao)



BASE FROM RECENT U.S.G.S. TOPOGRAPHIC QUADRANGLES
Bases reduced from 7 1/2' quadrangles, 1:24,000 to the scale of 1:48,000; contour intervals, 10, 20, 25, and 40 feet.

DRAFTED BY BETTY LINDGREN, VIVIAN MUSTON

SYMBOLS

Contact; solid where accurately located; long dashed where well located; short dashed where approximate or indefinite, dotted where concealed, poorly located, or gradational.

50

Fault showing dip; fracture zone of fault where wide enough to have mappable bounds is shown by double line with hachures. Shown by solid line where accurately located; long dashed where well located, short dashed where approximate or indefinite, dotted where concealed or poorly located; queried where inferred.

◆ ◆ ◆ ◆ ◆ ◆

Approximate location of ground-water barrier

50

Strike and dip of bedding; where vertical; where followed by (20') indicates depth below surface where strike and dip was recorded.

70

Strike and dip of foliation, where vertical

Syncline showing direction of plunge

Anticline showing direction of plunge

Note: Data used for map compilation is believed by the author to be the most reliable available at time of compilation, January, 1974.

This PRELIMINARY map is subject to revision.
It has not been reviewed for conformity with
U.S. Geological Survey standards and nomenclature.

GENERALIZED GEOLOGIC MAP OF SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

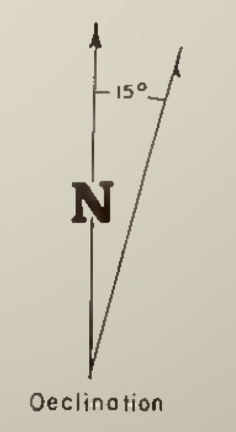
Compilation By D. M. Morton, 1974
U. S. Geological Survey

SCALE 1:48,000

0 1 2 3 4 Miles

0 10,000 Feet

0 1 2 Kilometers



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THOMAS E. GAY JR., ACTING STATE GEOLGIST

STATE OF CALIFORNIA
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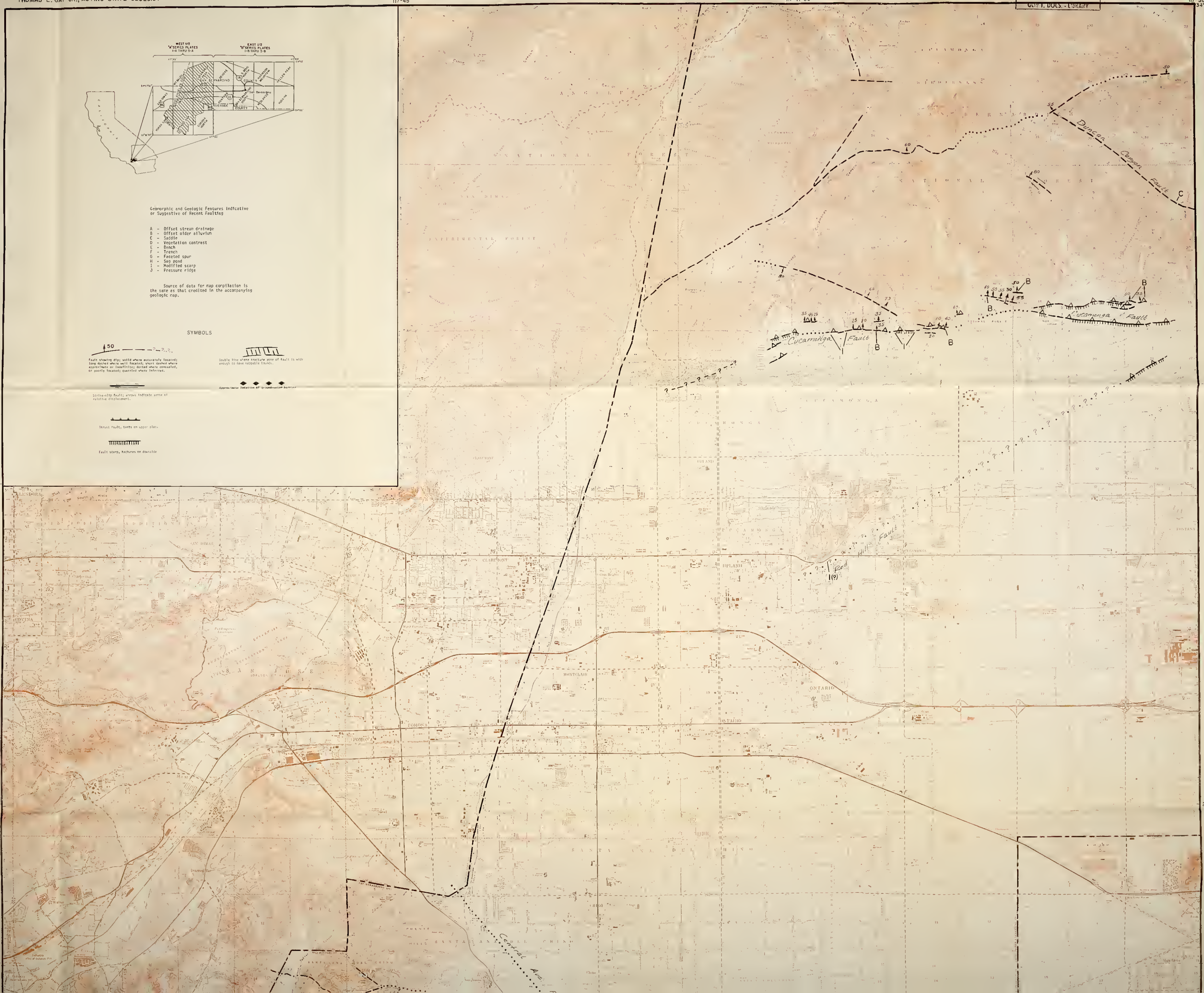


Geomorphic and Geologic Features Indicative
or Suggestive of Recent Faulting

A - Offset stream drainage
B - Offset older alluvium
C - Saddle
D - Vegetation contrast
E - Bench
F - Trench
G - Faceted spur
H - Sag pond
I - Modified scarp
J - Pressure ridge

Source of data for map compilation is the same as that credited in the accompanying geologic map.

SYMBOLS

Fault showing dip; solid where accurately located; long dashed where well located; short dashed where approximate or indefinite; dotted where concealed, or poorly located; queried where inferred.

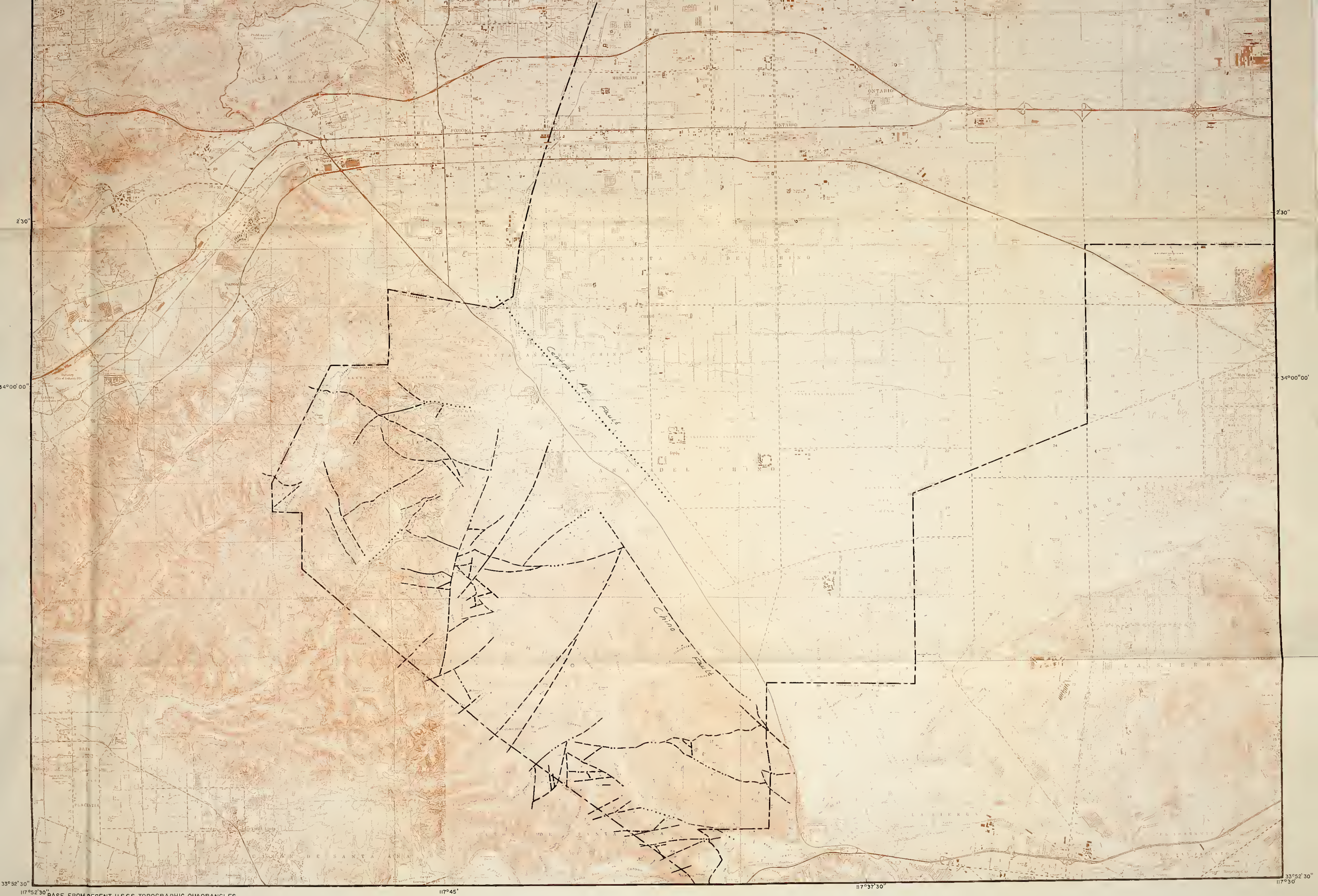
Double line where fracture zone of fault is wide enough to have mappable bounds.

Strike-slip fault; arrows indicate sense of relative displacement.

Approximate location of ground-water barrier

Thrust fault, barbs on upper plate

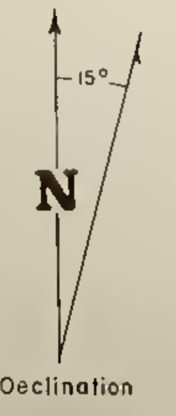
Fault scarp, hachures on downside



BASE FROM RECENT U.S.G.S. TOPOGRAPHIC QUADRANGLES
Bases reduced from 7 1/2' quadrangles, 1:24,000 to the scale of 1:48,000; contour intervals, 10, 20, 25, and 40 feet.

GENERALIZED FAULT MAP OF SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

Compilation By D. M. Morton, 1974
U. S. Geological Survey



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It has not been reviewed for conformity with
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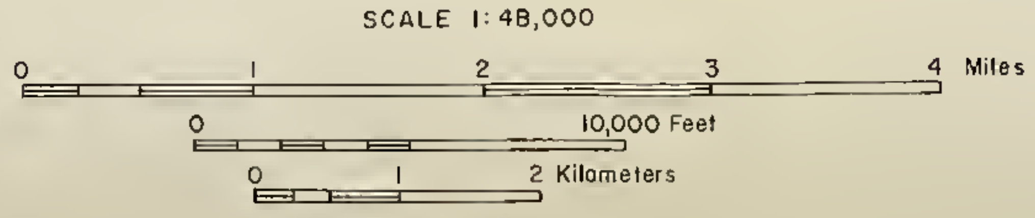

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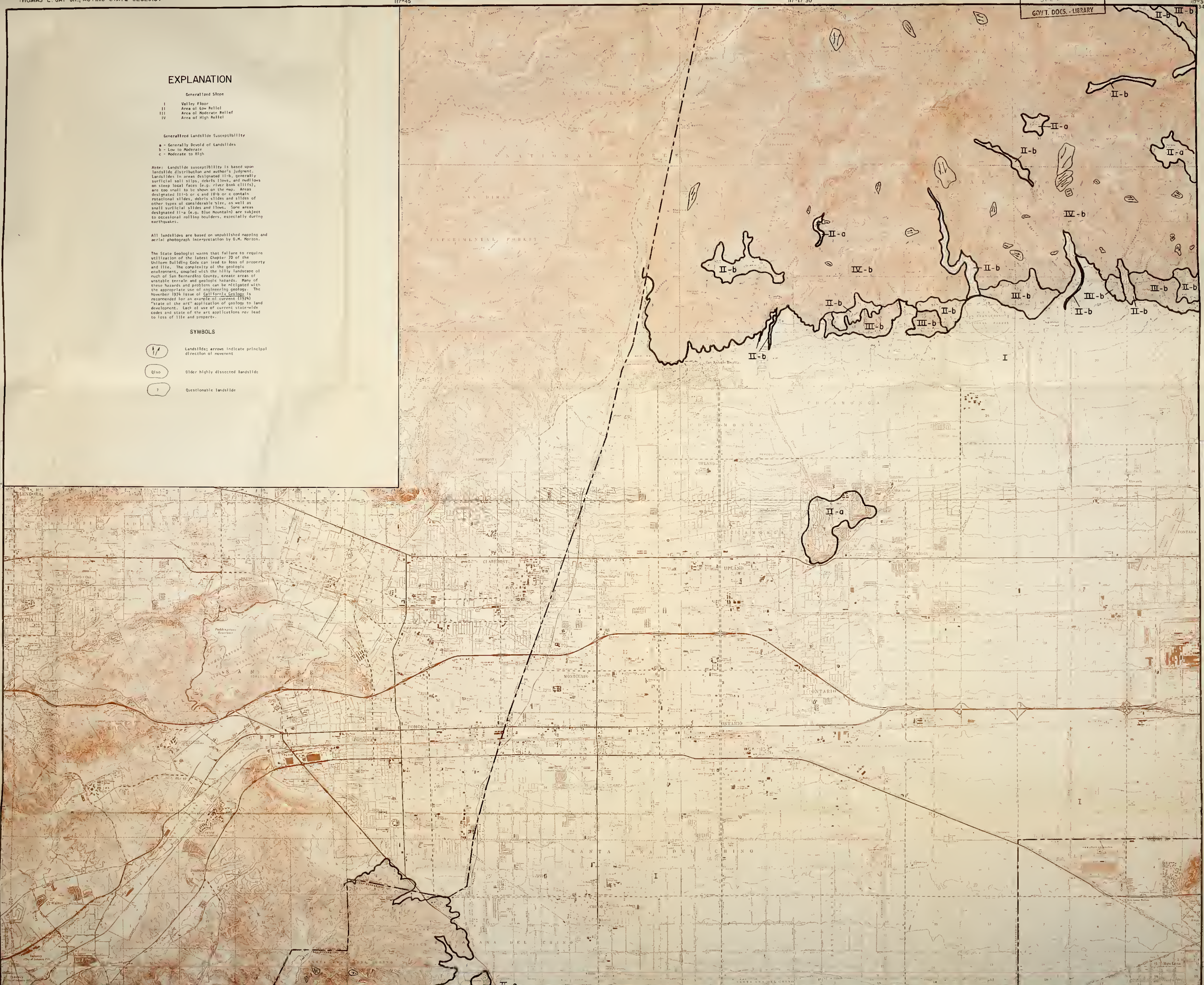


EXPLANATION

Generalized Slope

I	Valley Floor
II	Area of Low Relief
III	Area of Moderate Relief
IV	Area of High Relief

Generalized Landslide Susceptibility

a - Generally Devoid of Landslides
b - Low to Moderate
c - Moderate to High

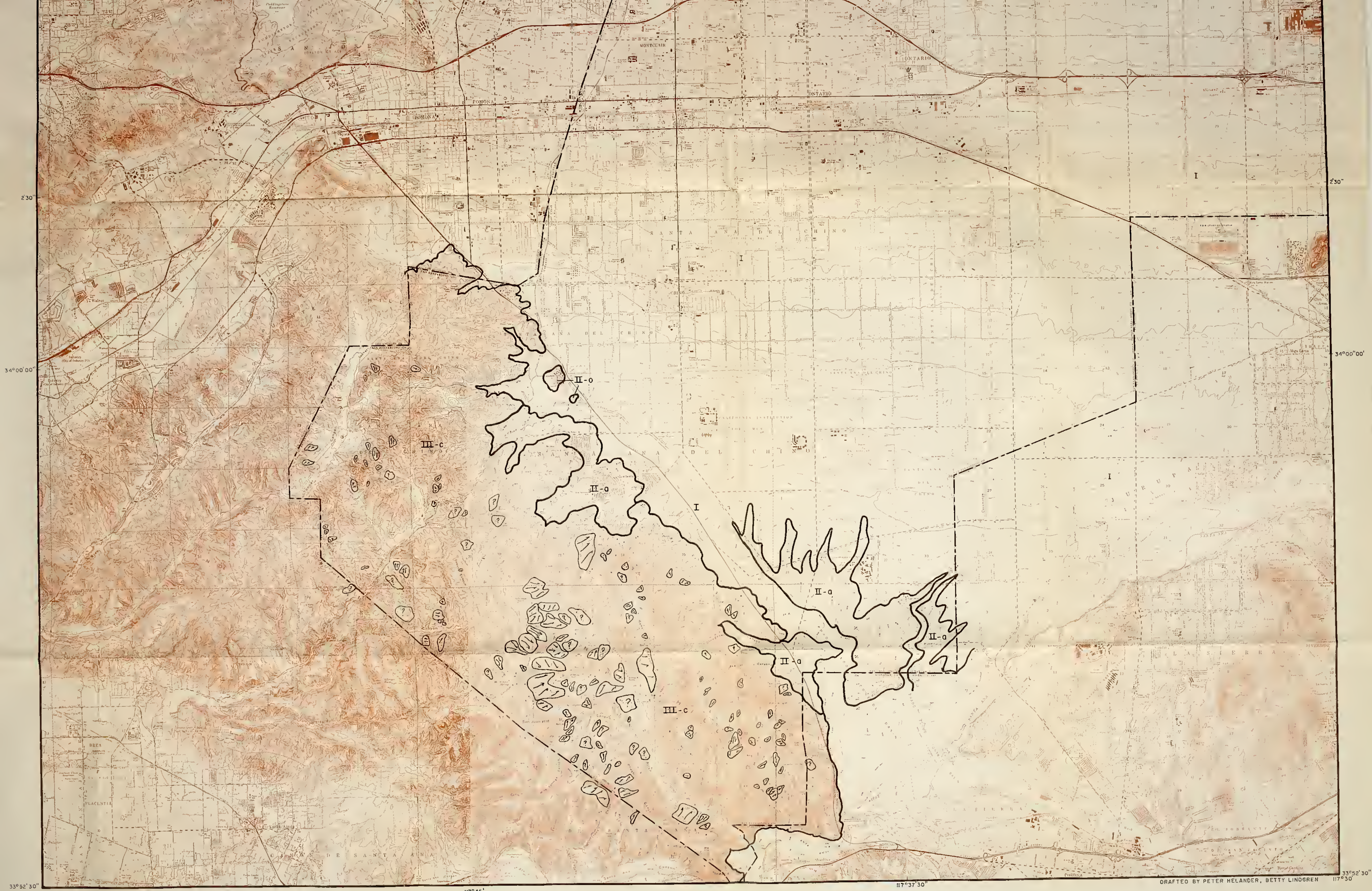
Note: Landslide susceptibility is based upon landslide distribution and author's judgment. Landslides in areas designated II-b, generally surficial soil slips, debris flows, and mudflows on steep local faces (e.g. river bank cliffs), are too small to be shown on the map. Areas designated III-b or c and IV-b or c contain rotational slides, debris slides and slides of other types of considerable size, as well as small surficial slides and flows. Some areas designated II-a (e.g. Blue Mountain) are subject to occasional rolling boulders, especially during earthquakes.

All landslides are based on unpublished mapping and aerial photograph interpretation by D.M. Morton.

The State Geologist warns that failure to require utilization of the latest Chapter 70 of the Uniform Building Code can lead to loss of property and life. The complexity of the geologic environment, coupled with the hilly landscape of much of San Bernardino County, create areas of unstable terrain and geologic hazards. Many of these hazards and problems can be mitigated with the appropriate use of engineering geology. The November 1974 issue of California Geology is recommended for an example of current (1974) "state of the art" application of geology to land development. Lack of use of current state-wide codes and state of the art applications may lead to loss of life and property.

SYMBOLS

↑↗	Landslide; arrows indicate principal direction of movement
Qlso	Older highly dissected landslide
?	Questionable landslide

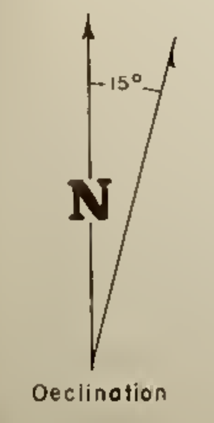


BASE FROM RECENT U.S.G.S. TOPOGRAPHIC QUADRANGLES
Bases reduced from 7 1/2' quadrangles, 1:24,000 to the scale of 1:48,000; contour intervals, 10, 20, 25, and 40 feet.

DRAFTED BY PETER HELANDER, BETTY LINDGREN

MAJOR LANDSLIDES AND GENERALIZED RELATIVE SLOPE STABILITY MAP, SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

By D. M. Morton, 1974
U. S. Geological Survey



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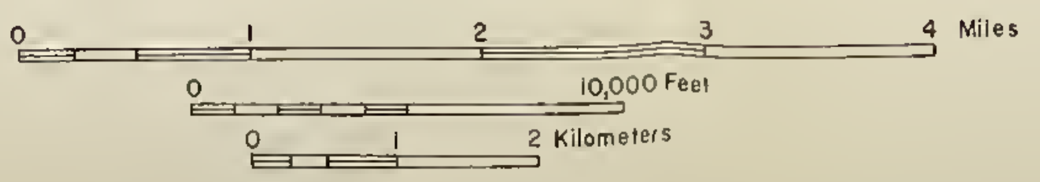
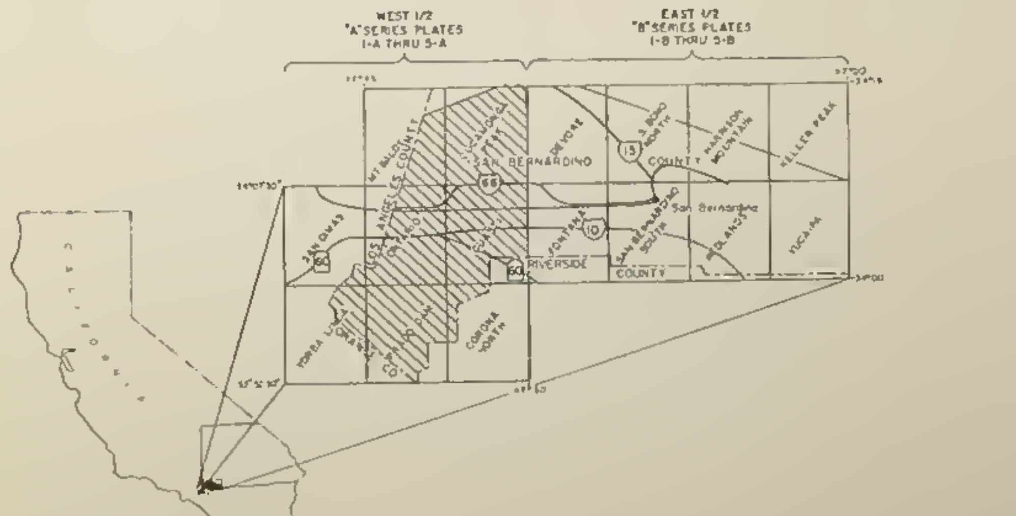
SCALE 1:48,000





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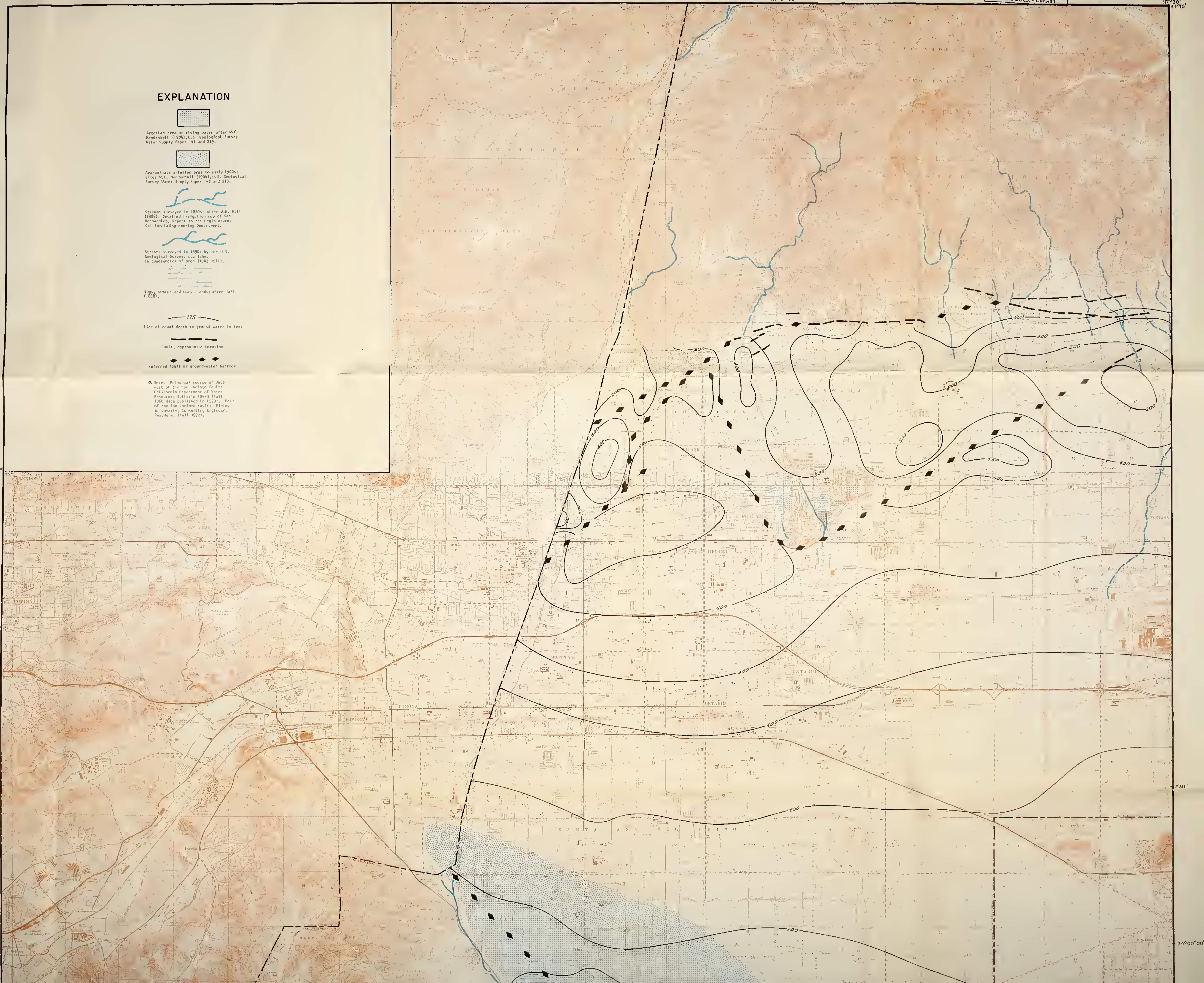


EXPLANATION

▨ Artesian area or rising water after W.C. Mendenhall (1904), U.S. Geological Survey Water Supply Paper 142 and 219.

▨ Approximate artesian area in early 1900s: after W.C. Mendenhall (1904), U.S. Geological Survey Water Supply Paper 142 and 219.

Streams surveyed in 1880s; after W.H. Hall (1888), Detailed irrigation map of San Bernardino, Report to the Legislature: California Engineering Department.

Streams surveyed in 1890s by the U.S. Geological Survey, published in quadrangles of area (1903-1911).

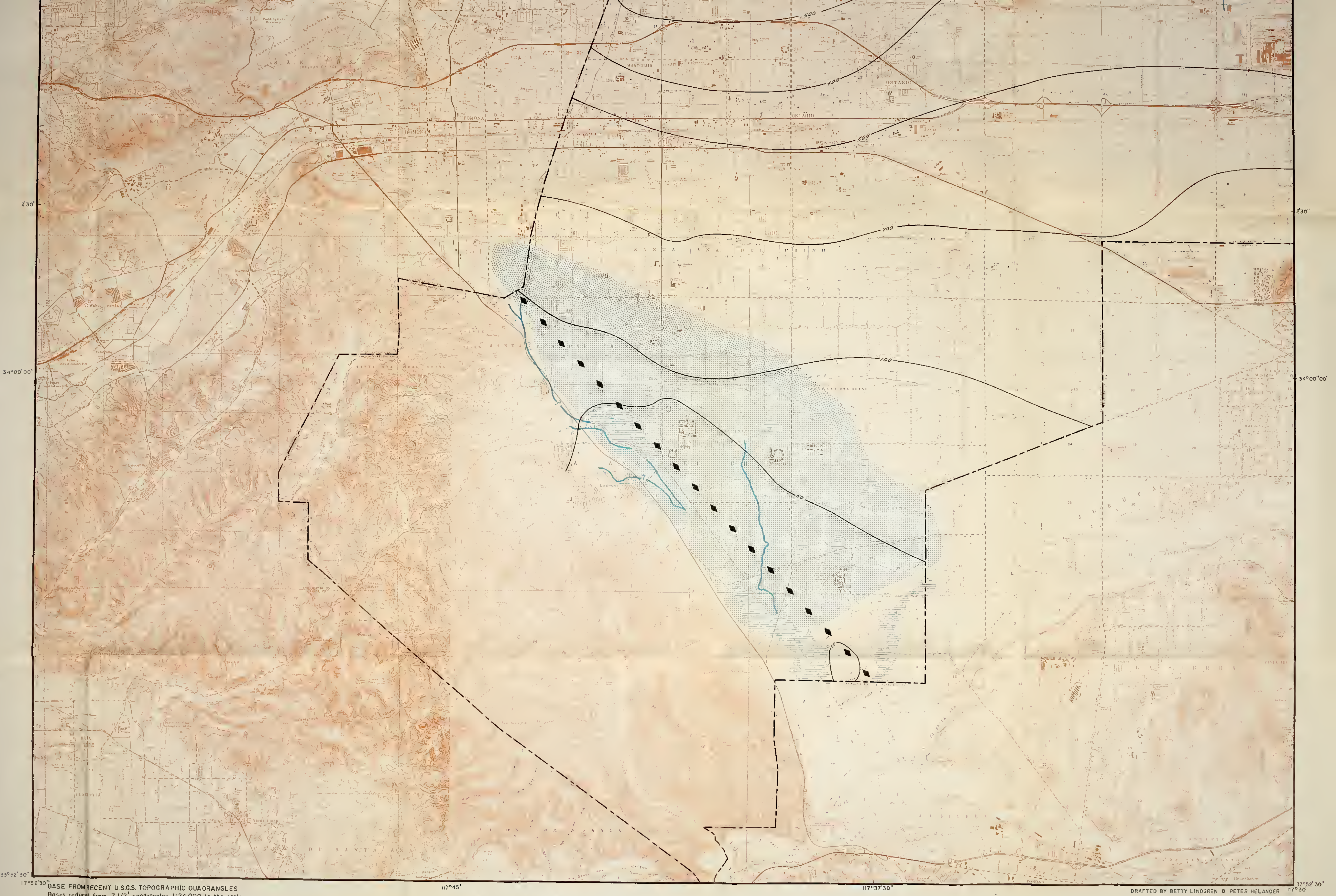
Bogs, swamps and marsh lands; after Hall (1888).

—175— Line of equal depth to ground water in feet

— — — Fault, approximate location

◆ ◆ ◆ ◆ Inferred fault or ground-water barrier

*Note: Principal source of data west of the San Jacinto fault: California Department of Water Resources Bulletin 104-3 (Fall 1960 data published in 1970). East of the San Jacinto fault: Finley B. Lavarly, Consulting Engineer, Pasadena, (Fall 1972).



BASE FROM RECENT U.S.G.S. TOPOGRAPHIC QUADRANGLES
Bases reduced from 7 1/2' quadrangles, 1:24,000 to the scale of 1:48,000; contour intervals, 10, 20, 25, and 40 feet.

DRAFTED BY BETTY LINDGREN & PETER HELANDER

MAP SHOWING SURFACE WATERS AND MARSHES IN THE LATE 1800s, AND GENERALIZED DEPTH TO GROUND WATER (1960),*UPPER SANTA ANA VALLEY, SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

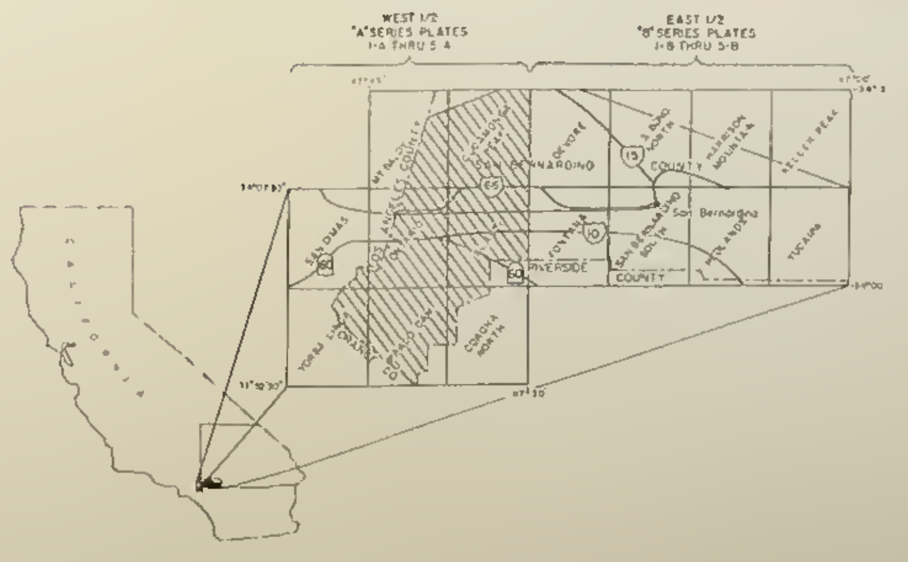
Compiled By Donald L. Fife, 1974

SCALE 1 48,000

0 1 2 3 4 Miles

0 10,000 Feet

0 1 2 Kilometers



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THOMAS E. GAY JR., ACTING STATE GEOLOGIST

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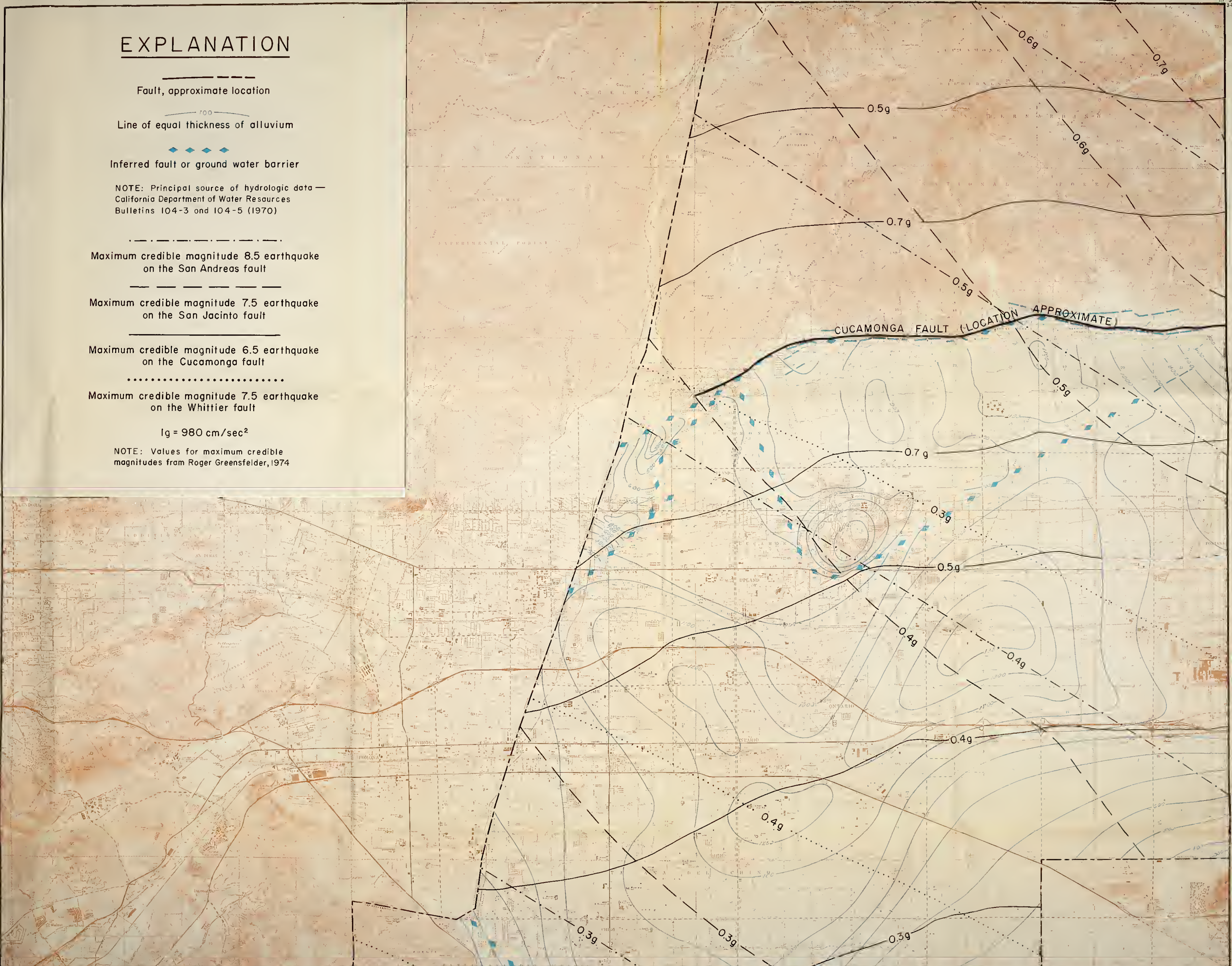


EXPLANATION

Fault, approximate location

Line of equal thickness of alluvium

Inferred fault or ground water barrier

NOTE: Principal source of hydrologic data — California Department of Water Resources Bulletins 104-3 and 104-5 (1970)

Maximum credible magnitude 8.5 earthquake on the San Andreas fault

Maximum credible magnitude 7.5 earthquake on the San Jacinto fault

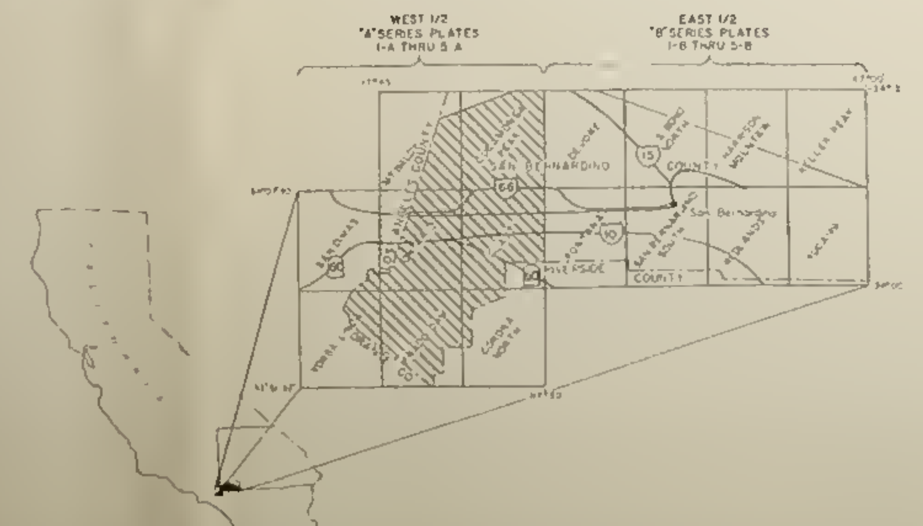
Maximum credible magnitude 6.5 earthquake on the Cucamonga fault

Maximum credible magnitude 7.5 earthquake on the Whittier fault

1g = 980 cm/sec²

NOTE: Values for maximum credible magnitudes from Roger Greensfelder, 1974

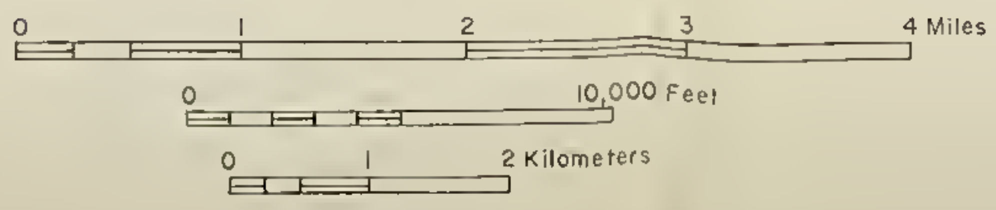
BASE FROM RECENT U.S.G.S. TOPOGRAPHIC QUADRANGLES
Bases reduced from 7 1/2' quadrangles, 1:24,000 to the scale of 1:48,000; contour intervals, 10, 20, 25, and 40 feet.

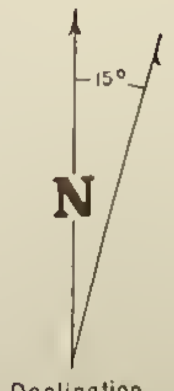


GENERALIZED MAP SHOWING THICKNESS OF FRESH-WATER BEARING ALLUVIUM, UPPER SANTA ANA VALLEY AND MAXIMUM CREDIBLE ROCK ACCELERATION FROM EARTHQUAKES IN THE VICINITY OF SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

By Donold L. Fife and Donold A. Rodgers, 1974

SCALE 1 48,000





DRAFTED BY BETTY LINDGREN & PETER HELANDER

THICKNESS OF FRESH-WATER BEARING ALLUVIUM
COMPILED BY DONALD L. FIFE, 1974

ROCK ACCELERATION PREPARED BY
DONALD A RODGERS, 1974

CALIFORNIA DIVISION OF MINES AND GEOLOGY
THOMAS E. GAY JR., ACTING STATE GEOLOGIST

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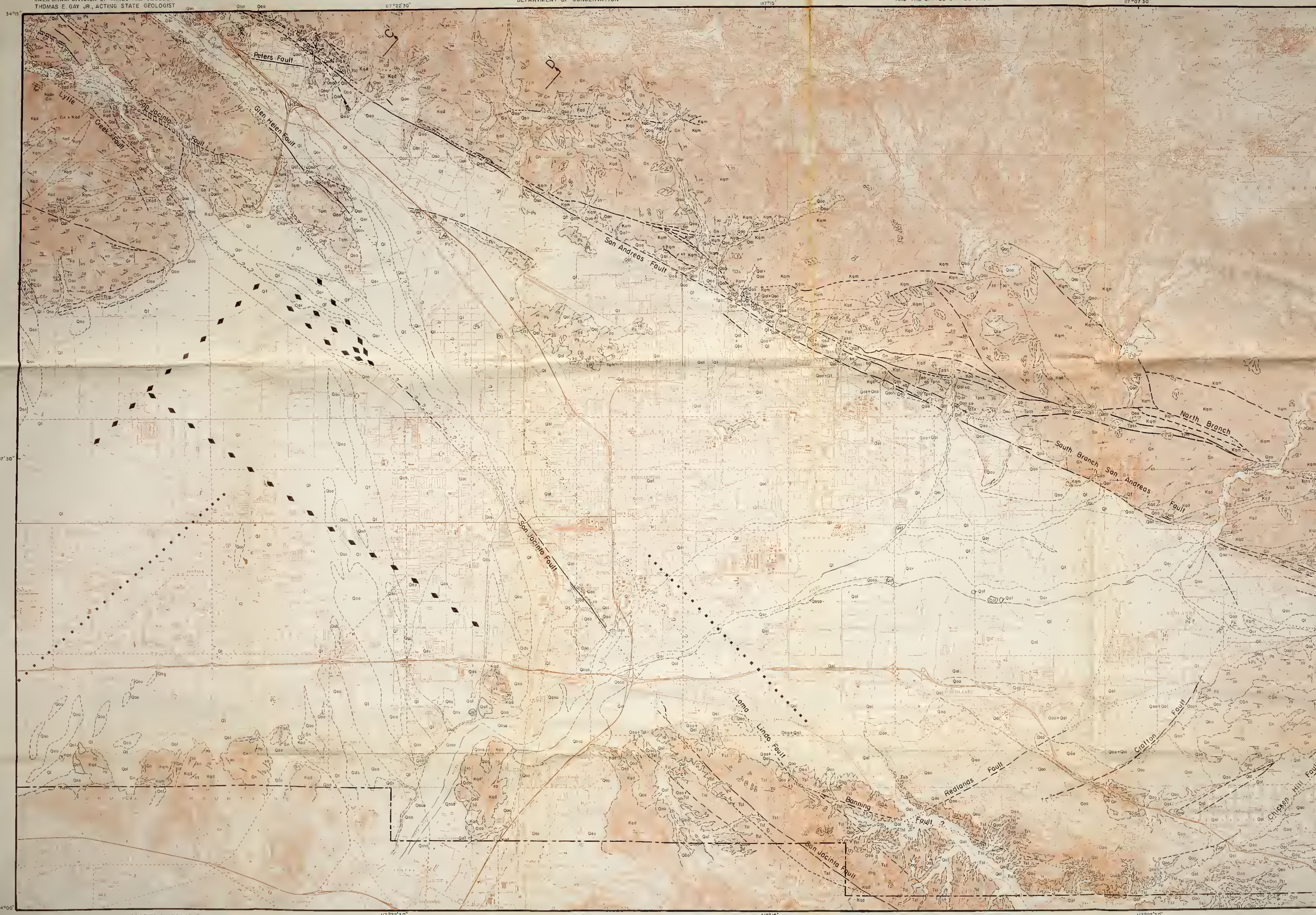

BASE FROM RECENT U.S.G.S TOPOGRAPHIC QUADRANGLES
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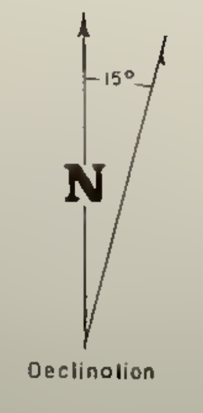

GENERALIZED GEOLOGIC MAP OF SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

Compilation By D. M. Morton, 1974
U. S. Geological Survey

SCALE 1:48,000

0 1 2 3 4 Miles
0 10,000 Feet
0 1 2 Kilometers

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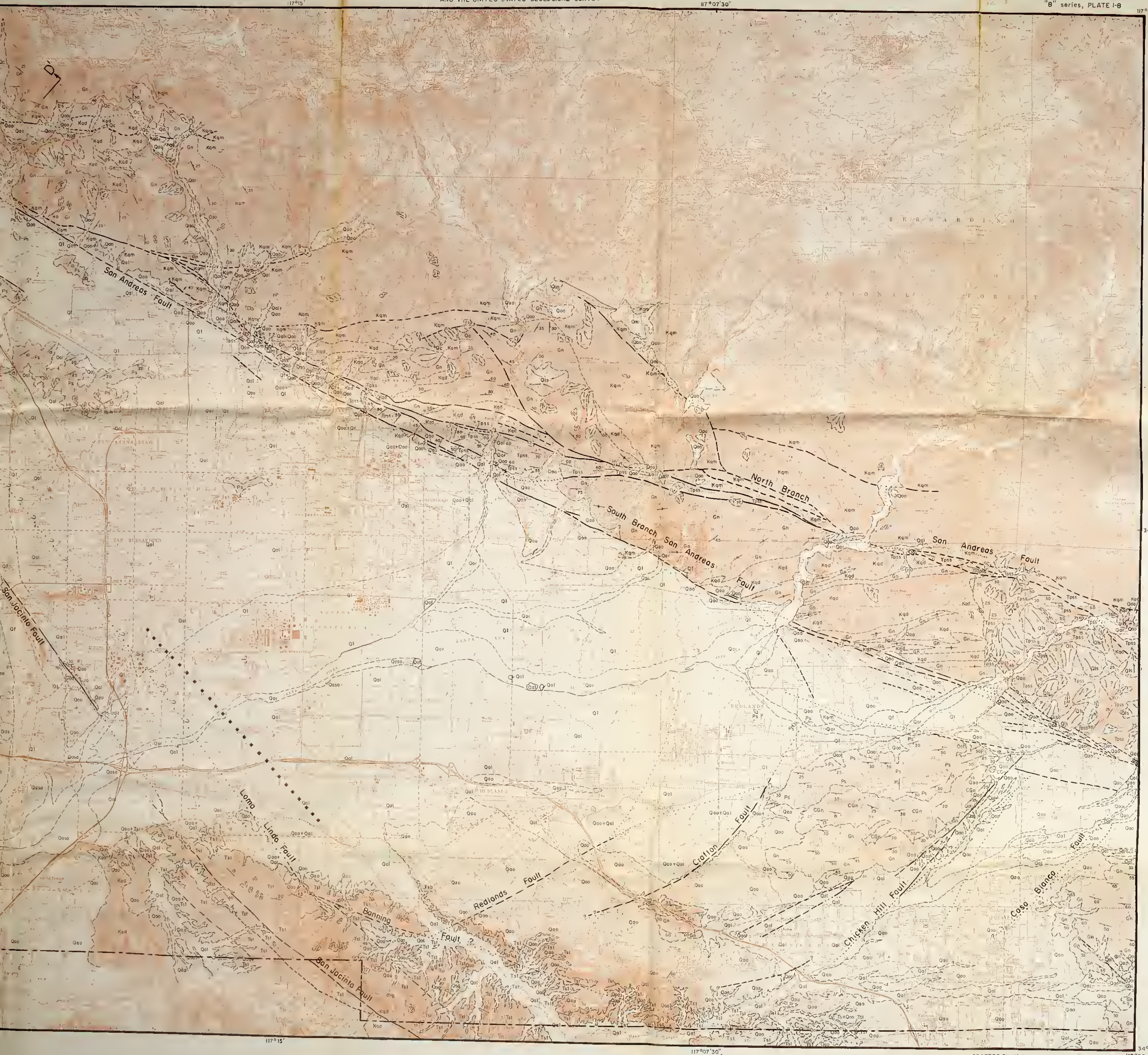

DRAFTED BY VIVIAN MUSTON, BETTY LINDGREN 117°30

GENERALIZED GEOLOGIC MAP OF SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

Compilation By D. M. Morton, 1974
U. S. Geological Survey

SCALE 1:48,000

0 1 2 3 4 Miles
0 10,000 Feet
0 1 2 Kilometers

UNIVERSITY OF CALIFORNIA DAVIS

EXPLANATION

SURFICIAL DEPOSITS

Qaf
Artificial fill

Major occurrences of man-placed fill, both compacted and uncompacted. Includes major highway and sanitary fills, quarry refuse, and slag.

Qar
Active river channel alluvium

Unconsolidated alluvium of major drainage channels subject to, or recently subject to streamflood, especially near mountains and where not controlled by flood control measures. Many of the channels are subject to course shifting during periods of streamflood. Alluvium devoid, or nearly devoid of vegetation. Ranges from coarse bouldery alluvium near mountains to sandy alluvium in valley areas removed from mountains.

Qaso
Santa Ana River channel alluvium

Unconsolidated sandy alluvium of the Santa Ana River channel. Apparently not as recently subject to fluvial reworking as the adjacent Qar.

Qf
Alluvial fan deposits

Unconsolidated deposits of young coarse alluvium, radiating from mountain fronts. Alluvium ranges from coarse bouldery alluvium near mountain front to pebbly and cobbly alluvium where it grades into undifferentiated younger alluvium.

Qal
Younger alluvium undifferentiated

Unconsolidated alluvium of the valley area and along some major drainage courses within the highlands surrounding the valley.

Qc
Colluvium and talus

Major occurrences of unconsolidated coarse rocky colluvium and talus.

Qws
Wind blown sand areas

Major areas subject to active blowing sand which include some small sand dunes and other thin concentrations of wind blown sand. Arrows (←—) indicate predominate direction of sand transport.

Holocene

Qls
Qlso
Landslide

Qls = major landslides; includes landslide and scarp area where mappable. Landslide deposits consist of unconsolidated highly fragmented rock. Smaller landslides are outlined and indicated by arrows (——▸) without Qls symbol. Questionable landslides are queried. Arrows indicate principal direction of landslide movement.
Qlso = older highly dissected landslide deposits.

Qds
Dune sand

Major deposits of unconsolidated dune sand. Most deposits are stabilized with a vegetation cover. Locally reactivated where vegetative cover has been removed or destroyed.

Qoa
Older alluvium undifferentiated

Deposits of older alluvium which range from unconsolidated older alluvial fan deposits (fanglomerate) to indurated older decomposed clay-rich alluvium.

Pleistocene

QUATERNARY

SEDIMENTARY ROCKS

Tsl
San Timoteo Beds

Mostly gray to reddish, poorly bedded, unconsolidated to lithified nonmarine conglomeratic and sandy sediment.

Tcg
Conglomerate and sandstone

Late Tertiary (?) nonmarine sediments within the Cucamonga and San Andreas fault zones. Unconsolidated gray conglomerate in the eastern part of the Cucamonga fault zone. Consolidated cream, tan, and maroon sandstone and conglomerate in the San Andreas fault zone west of Waterman Canyon.

Tpss
Potato Sandstone (Mill Creek Formation of Gibson, 1971)

Predominantly gray, lithified nonmarine sandstone and conglomerate with minor limestone.

Pliocene

Tp: **Tpsc**, **Tpy**, **Tps**
Puente Formation

Tp = Puente Formation undifferentiated. Gray to brown marine siltstone, sandstone, and conglomerate.
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Tps = Soquel Member. Predominantly gray to light brown massive to well bedded marine sandstone with minor conglomerate and conglomeratic sandstone.

Tt
Topanga Formation

Predominantly white to light brown marine sandstone with lenses of conglomerate and conglomeratic sandstone.

Miocene

Tvs
Vaqueros and Sespe Formations undifferentiated

Reddish-brown marine and nonmarine (?) sandstone.

Eocene to Miocene

TERTIARY

CENOZOIC

PLUTONIC ROCKS

Td
Diabase

Diabase body intruding Miocene quartz monzonite. Black fine- to coarse-grained diabase.

Tqm
Miocene quartz monzonite

Whitish medium grained massive biotite quartz monzonite and granodiorite. Intrudes Pelona Schist.

Miocene
TERTIARY
CENOZOIC

Kqm / **CKqm**
Cretaceous quartz monzonite

Kqm = gray medium- to coarse-grained, massive to foliated quartz monzonite and granodiorite. Includes minor amounts of quartz diorite and gneiss.
CKqm = rock that has been cataclastically deformed.

Kqd / **CKqd**
Quartz diorite

Kqd = gray, medium- to coarse-grained generally foliated biotite-hornblende quartz diorite. Includes minor amounts of quartz granodiorite and gneiss.
CKqd = rock that has been cataclastically deformed.

CRETACEOUS
MESOZOIC

METAMORPHIC ROCKS

Ps
Pelona Schist

Gray to dark green, well to poorly foliated fine grained schist and quartzite. Commonly well layered. Intruded by the Miocene quartz monzonite unit; generally considered either Mesozoic or Precambrian in age.

Gn / **Gnm** / **CGn**
Gneiss and schist

Gn = highly varied mixture of dark colored, poor to well layered, poorly to well foliated gneiss and schist; generally biotite bearing. Structurally complicated. Locally abundant marble layers.
Gnm = largest marble layers.
CGn = rock that has been cataclastically deformed. Pre-Cretaceous, generally considered Precambrian in age.

Gr / **CGr**
Granulitic Rock

Gr = highly varied mixture of extremely deformed layered, metamorphic rock characterized by presence of pyroxene and hornblende. Locally abundant marble layers and local quartzite and amphibolite.
CGr = rock that has been cataclastically deformed. Pre-Cretaceous, generally considered Precambrian in age.

Note: Where area is underlain by undifferentiated mixture of two map units composite symbol is used (e.g. Qal and Qao)

SYMBOLS

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Contact, solid where accurately located; long dashed where well located; short dashed where approximate or indefinite; dotted where concealed, poorly located, or gradational.

50
Fault showing dip, fracture zone of fault where wide enough to have mappable bounds is shown by double line with hachures. Shown by solid line where accurately located; long dashed where well located, short dashed where approximate or indefinite, dotted where concealed or poorly located, queried where inferred

◆ ◆ ◆ ◆ ◆ ◆
Approximate location of ground water-barrier

■ ■ ■ ■ ■ ■ ■
Approximate location of fault inferred from seismic activity.

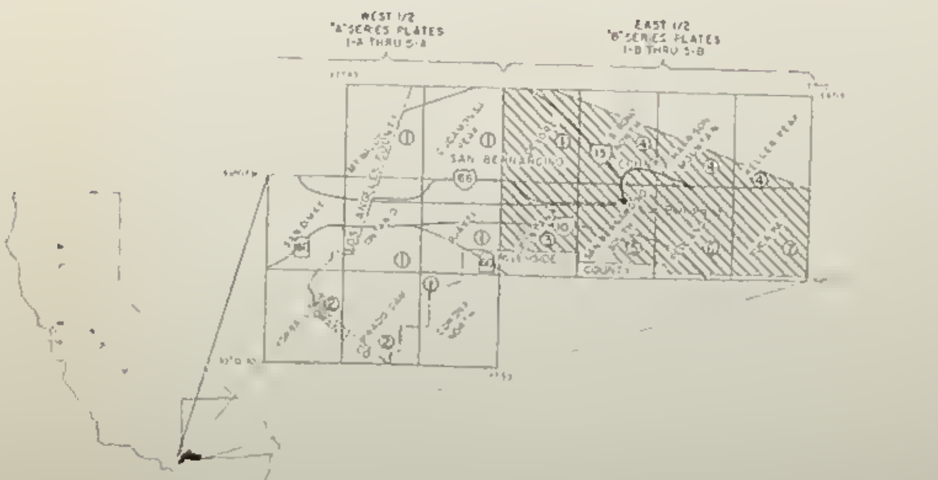
50
Strike and dip of bedding; where vertical —+—, where followed by [20'] indicates depth below surface where strike and dip was recorded

70
Strike and dip of foliation, where vertical

Syncline showing direction of plunge

Anticline showing direction of plunge

Note: Data used for map compilation is believed by the author to be the most reliable available at time of compilation, January, 1974.



Index to Geologic Mapping

1) Morton, D.M., U.S. Geological Survey unpublished mapping; Additional fault data from Hadley, 1973, Sharp 1972, Woodford, Shelton, and Moran, 1944, and Dutcher and Garrett, 1963.

2) Durham and Yerkes, 1964; Additional fault data from Woodford, Shelton, and Moran, 1944, and Dutcher and Garrett, 1963.

3) Mackevett, 1951; Morton, D.M., U.S. Geological Survey unpublished mapping.

4) Dibblee, T.W., Jr., U.S. Geological Survey unpublished mapping; additional fault data from Dutcher and Garrett, 1963.

5) Dutcher and Burnham, 1959; Morton, D.M., U.S. Geological Survey unpublished mapping; additional fault data from Hadley 1973, and Sieh et al., 1973.

6) Dutcher and Burnham 1959; Dibblee, T.W., Jr. U.S. Geological Survey unpublished mapping; Morton, D.M., U.S. Geological Survey unpublished mapping; additional fault data from Hope 1969.

7) Dibblee 1968; additional fault data from Dutcher and Burnham, 1959; Hope 1969.

Note: All landslides from Morton, D.M., U.S. Geological Survey unpublished mapping

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THOMAS E. GAY JR., ACTING STATE GEOLOGIST

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

PREPARED IN COOPERATION WITH THE
SAN BERNARDINO COUNTY PLANNING DEPARTMENT
AND THE UNITED STATES GEOLOGICAL SURVEY

SPECIAL REPORT 113
"B" series, PLATE 2B

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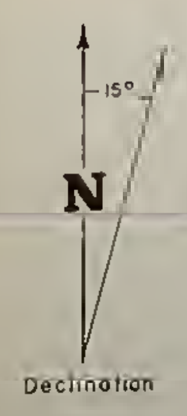
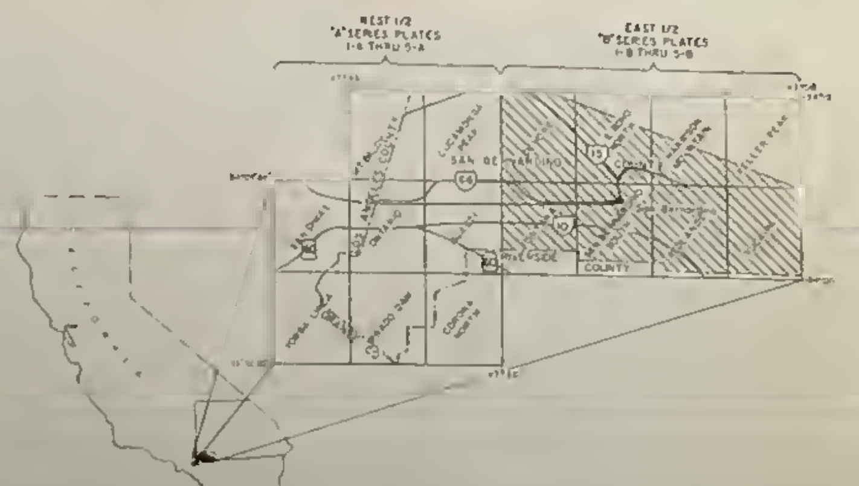
BASE FROM RECENT U.S.G.S TOPOGRAPHIC QUADRANGLES
Bases reduced from 7 1/2' quadrangles, 1:24,000 to the scale of 1:48,000; contour intervals, 10, 20, 25, and 40 feet.

This PRELIMINARY map is subject to revision.
It has not been reviewed for conformity with
U.S. Geological Survey standards and nomenclature.





GENERALIZED FAULT MAP OF SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

Compilation By D. M. Morton, 1974
U. S. Geological Survey

SCALE 1:48,000

0 1 2 3 4 Miles

0 10,000 Feet

0 1 2 Kilometers

DRAFTED BY PETER HELANDER, BETTY LINDGREN

SYMBOLS

50

Fault showing dip; solid where accurately located; long dashed where well located; short dashed where approximate or indefinite; dotted where concealed, or poorly located; queried where inferred.

Strike slip fault; arrows indicate sense of relative displacement

Thrust fault; barbs on upper plate

Fault scarp, hachures on downside

Double line where fracture zone of fault is wide enough to have mappable traces

Approximate location of ground [illegible]

Approximate location of fault inferred from seismic activity

Geomorphic and Geologic Features Indicative or Suggestive of Recent Faulting

A - Offset stream drainage
B - Offset older alluvium
C - Saddle
D - Vegetation contrast
E - Bench
F - Trench
G - Faceted spur
H - Sag pond
I - Modified scarp
J - Pressure ridge

Source of data for map compilation is the same as that credited in the accompanying geologic map.

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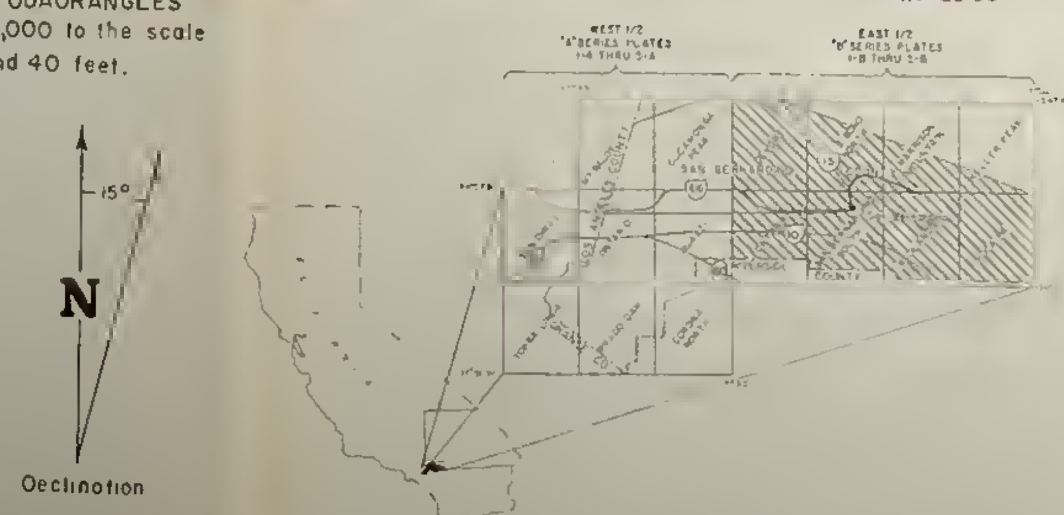
BASE FROM RECENT USGS TOPOGRAPHIC QUADRANGLES
Bases reduced from 7 1/2' quadrangles, 1:24,000 to the scale of 1:48,000; contour intervals, 10, 20, 25, and 40 feet.

DRAFTED BY PETER HELANDER, BETTY LINDGREN

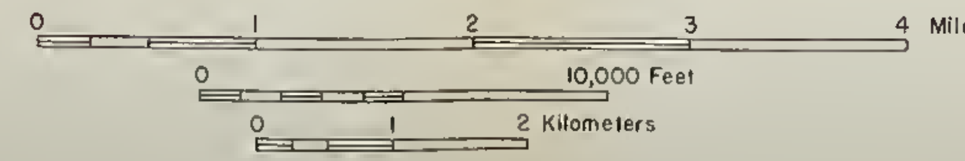
The State Geologist warns that failure to require utilization of the latest Chapter 70 of the Uniform Building Code can lead to loss of property and life. The complexity of the geologic environment, coupled with the hilly landscape of much of San Bernardino County, create areas of unstable terrain and geologic hazards. Many of these hazards and problems can be mitigated with the appropriate use of engineering geology. The November 1974 issue of California Geology is recommended for an example of current (1974) "state of the art" application of geology to land development. Lack of use of current state-wide codes and state of the art applications may lead to loss of life and property.



MAJOR LANDSLIDES AND GENERALIZED RELATIVE SLOPE STABILITY MAP, SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

By D. M. Morton, 1974
U. S. Geological Survey

SCALE 1:48,000



This PRELIMINARY map is subject to revision.
It has not been reviewed for conformity with
U.S. Geological Survey standards and nomenclature.

Generalized Slope

I	Valley Floor
II	Area of Low Relief
III	Area of Moderate Relief
IV	Area of High Relief

Generalized Landslide Susceptibility

a - Generally Devoid of Landslides
b - Low to Moderate
c - Moderate to High

Note: Landslide susceptibility is based upon landslide distribution and author's judgment. Landslides in areas designated II-b, generally surficial soil slips, debris flows, and mudflows on steep local faces (e.g. river bank cliffs), are too small to be shown on the map. Areas designated III-b or c and IV-b or c contain rotational slides, debris slides and slides of other types of considerable size, as well as small surficial slides and flows. Some areas designated II-a (e.g. Blue Mountain) are subject to occasional rolling boulders, especially during earthquakes.

All landslides are based on unpublished mapping and aerial photograph interpretation by D.M. Morton.

SYMBOLS

⬭	Landslide; arrows indicate principal direction of movement
⬭	Older highly dissected landslide
?	Questionable landslide

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DRAFTED BY BETTY LINDGREN & PETER HELANDER 117°30

BASE FROM RECENT U.S.G.S. TOPOGRAPHIC QUADRANGLES
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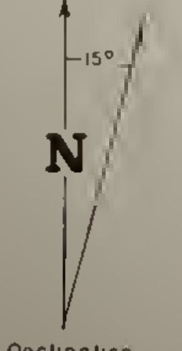

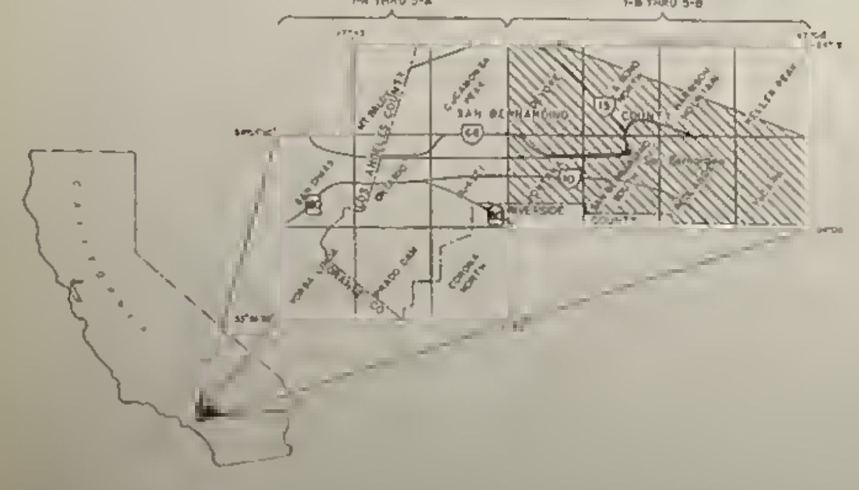

MAP SHOWING SURFACE WATERS AND MARSHES IN THE LATE 1800s, AND GENERALIZED DEPTH TO GROUND WATER (1960),* UPPER SANTA ANA VALLEY, SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

Compiled By Donald L. Fife, 1974

SCALE 1:48,000

0 1 2 3 4 Miles

0 10,000 Feet

0 1 2 Kilometers

EXPLANATION

☐ Artesian area or upper confining layer after L.C. Dutcher and A.A. Garrett (1963), U.S. Geological Survey Water Supply Paper 1419.

☐ Artesian area or rising water after W.C. Mendenhall (1904), U.S. Geological Survey Water Supply Paper 142 and 219.

▨ Approximate artesian area in early 1900s; after W.C. Mendenhall (1904), U.S. Geological Survey Water Supply Paper 142 and 219.

Streams surveyed in 1880s; after W.H. Hall (1888), Detailed Irrigation map of San Bernardino, Report to the Legislature: California Engineering Department.

Streams surveyed in 1890s by the U.S. Geological Survey, published in quadrangles of area (1903-1911).

Bogs, swamps and marsh lands; after Hall (1888).

—— 175 —— Line of equal depth to ground water in feet

— — — — Fault, approximate location

◆ ◆ ◆ ◆ Inferred fault or ground-water barrier

* Note: Principal source of data west of the San Jacinto fault: California Department of Water Resources Bulletin 104-3 (Fall 1960 data published in 1970). East of the San Jacinto fault: Finley B. Laverty, Consulting Engineer, Pasadena, (Fall 1972).

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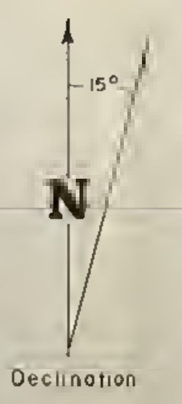
BASE FROM RECENT USGS TOPOGRAPHIC QUADRANGLES
Bases reduced from 7 1/2' quadrangles, 1:24,000 to the scale of 1:48,000; contour intervals, 10, 20, 25, and 40 feet.

THICKNESS OF FRESH-WATER BEARING ALLUVIUM
COMPILED BY DONALD L. FIFE, 1974

ROCK ACCELERATION PREPARED BY
DONALD A. RODGERS, 1974

WEST 1/2 "A" SERIES PLATES 1-A THRU 5-A
EAST 1/2 "B" SERIES PLATES 1-B THRU 5-B
SAN BERNARDINO
RIVERSIDE
COUNTY



DRAFTED BY BETTY LINDGREN & PETER HELANDER

GENERALIZED MAP SHOWING THICKNESS OF FRESH-WATER BEARING ALLUVIUM, UPPER SANTA ANA VALLEY AND MAXIMUM CREDIBLE ROCK ACCELERATION FROM EARTHQUAKES IN THE VICINITY OF SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

By Donald L. Fife and Donald A. Rodgers, 1974

SCALE 1:48,000

0 1 2 3 4 Miles

0 10,000 Feet

0 1 2 Kilometers

EXPLANATION

— · — · — · —
Maximum credible magnitude 8.5 earthquake on the San Andreas fault

— — — — —
Maximum credible magnitude 7.5 earthquake on the San Jacinto fault

————————
Maximum credible magnitude 6.5 earthquake on the Cucamonga fault

Note: Values for maximum credible magnitudes from Greensfelder, 1974

1g=980 cm/sec^2

▬ ▬ ▬ ▬
Fault, approximate location

Lines of equal thickness of alluvium

◆ ◆ ◆ ◆
Inferred fault or ground-water barrier

Note: Principal source of hydrologic data — California Department of Water Resouces Bulletins 104-3 and 104-5 (1970)

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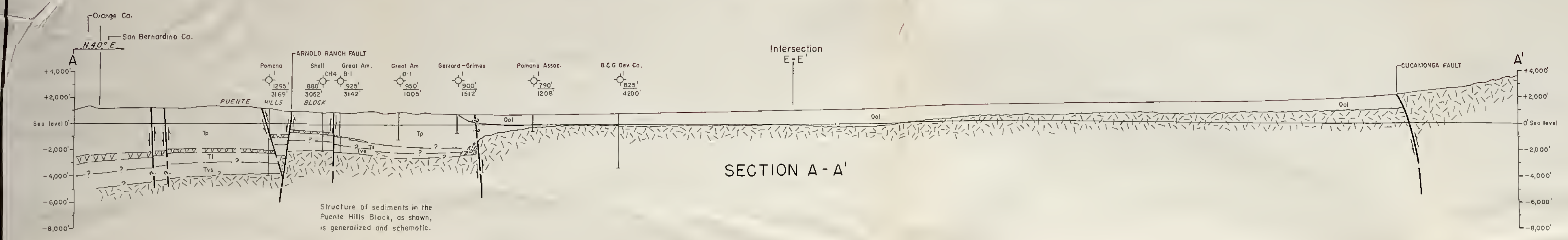
SECTION A - A'

Structure of sediments in the Puente Hills Block, as shown, is generalized and schematic.

SECTION B - B'

Structure of sediments in the Puente Hills Block, as shown, is generalized and schematic.

Chino fault not apparent at the surface, if present at this location obscured by Qal.

Location of faulting inferred from apparent ground water barrier and discontinuous surface rupture.

Dip of faulting at depth unknown, presumed to approach vertical.

SECTION C - C'

Structure of sediments in the Puente Hills Block, as shown, is generalized and schematic.

PREPARED IN COOPERATION WITH THE
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GEOLOGIC SECTIONS
UPPER SANTA ANA VALLEY
SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

BY E. C. SPROTTE AND D. L. FIFE, 1974

HORIZONTAL AND VERTICAL SCALE

0 8,000 FEET

0 1000 2000 3000 METERS

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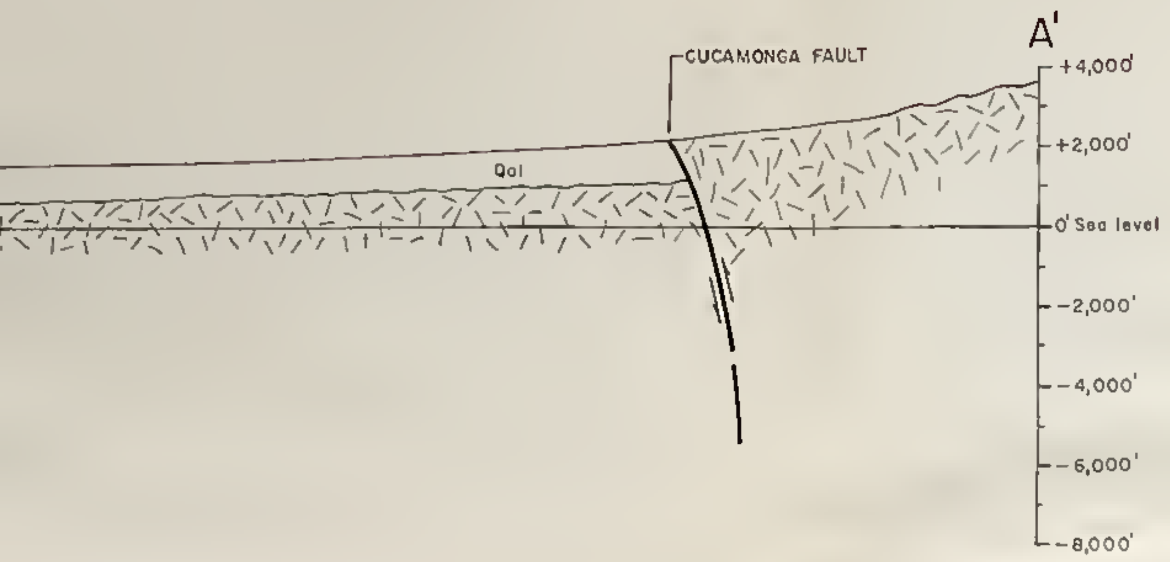

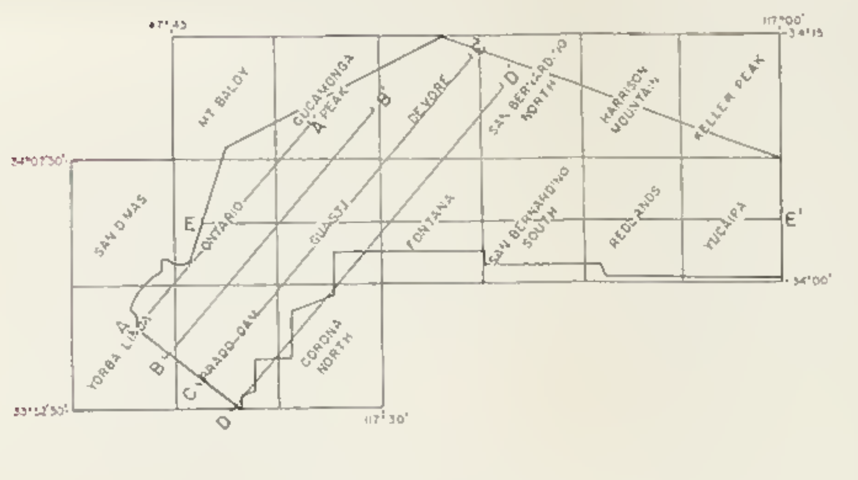

GEOLOGIC SECTION INDEX

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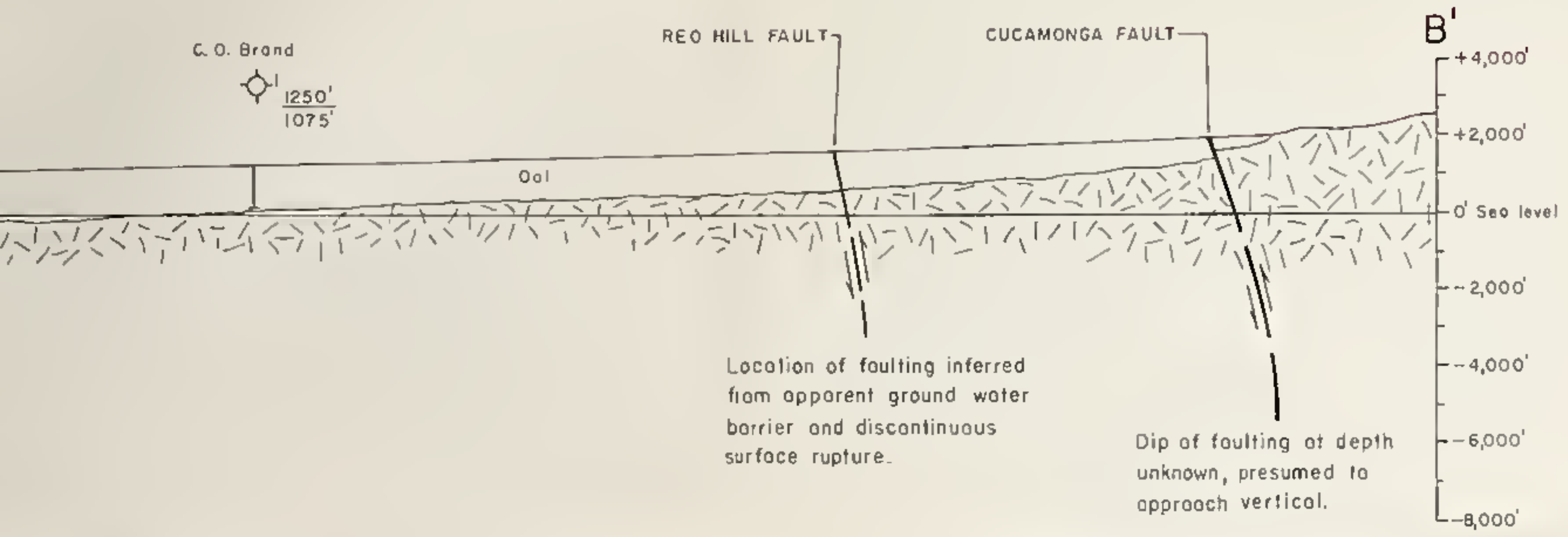
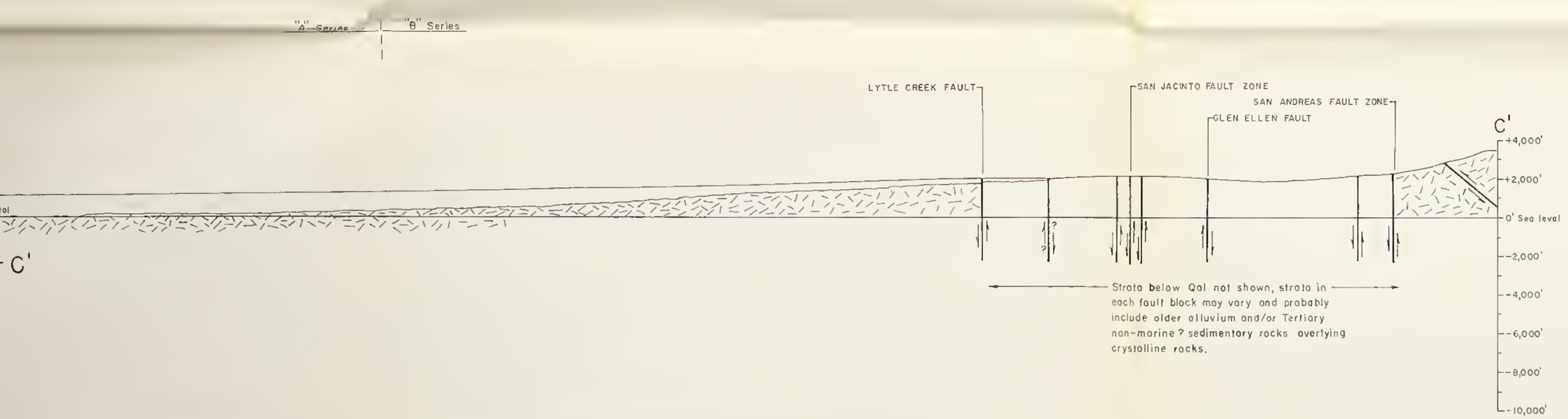
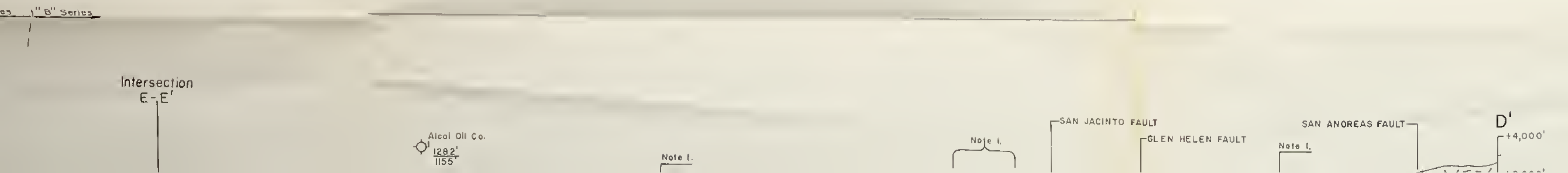


Location of faulting inferred from apparent ground water barrier and discontinuous surface rupture.

Dip of faulting at depth unknown, presumed to approach vertical.



Strata below Qal not shown, strata in each fault block may vary and probably include older alluvium and/or Tertiary non-marine ? sedimentary rocks overlying crystalline rocks.



STRATIGRAPHIC LEGEND

CENOZOIC

QUATERNARY

Qal
Alluvium and Quaternary non-marine sediments undifferentiated

TERTIARY

Miocene

Tp
Puente Formation undifferentiated, includes Sycamore Canyon, Yorba, Soquat and La Vida Members.

Tt
Topanga Formation, includes volcanic rocks consisting of andesite and basaltic flows and tuffs, shown as VVVV

Tvs
Vaqueros and Sespe Formations undifferentiated.

Paleocene Eocene

Tsa
Santiago Formation

Tst
Silverado Formation

MESOZOIC

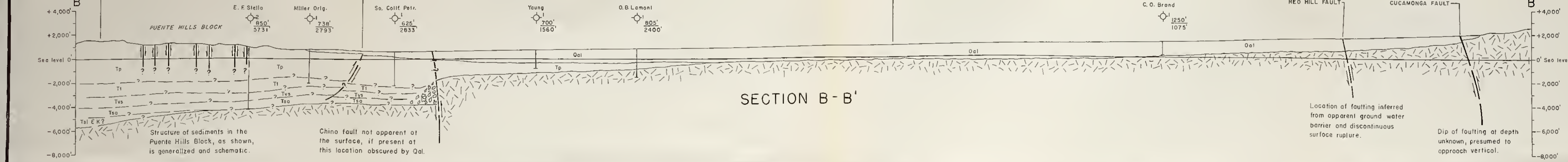
UPPER CRETACEOUS

K
Upper Cretaceous, undifferentiated. Probably includes Ladd Formation.

UPPER CRETACEOUS AND OLDER

Crystalline rock undifferentiated. Presumed to be Upper Cretaceous or older ? in age

— Unconformity

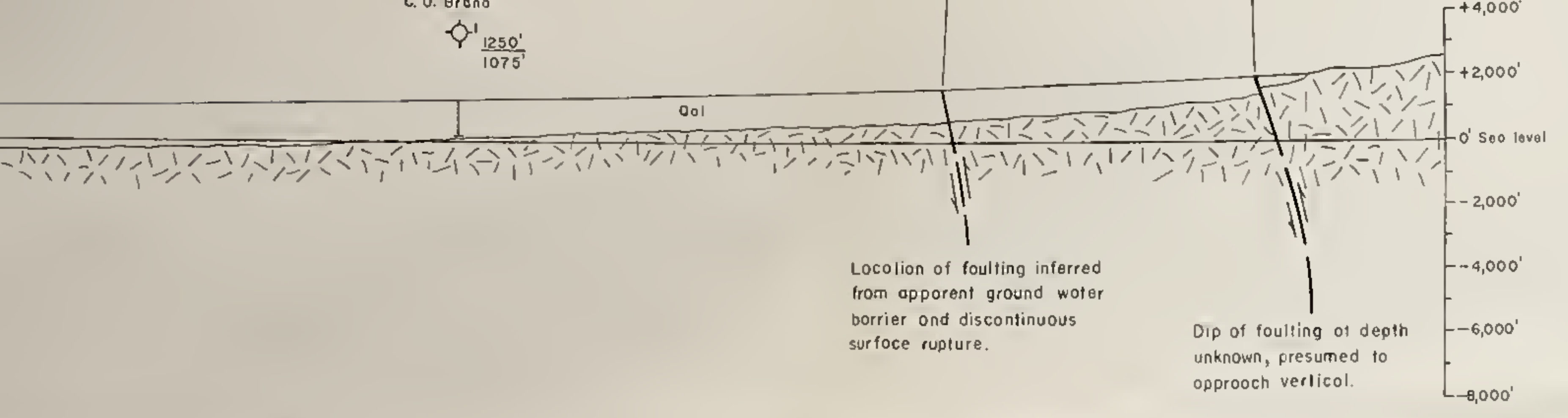

B
E. F. Stella
850'
5731'
Miller Orig.
738'
2793'
So. Calif Petr.
625'
2833'
Young
700'
1560'
O.B Lamont
805'
2400'
C. O. Brand
1250'
1075'
RED HILL FAULT
CUCAMONGA FAULT
B'
+4,000'
+2,000'
Sea level 0
-2,000'
-4,000'
-6,000'
-8,000'
PUENTE HILLS BLOCK
Tp
Tl
Tvs
Tso
Tsl E K?
Qal
Structure of sediments in the Puente Hills Block, as shown, is generalized and schematic.
Chino fault not apparent at the surface, if present at this location obscured by Qal.
Location of faulting inferred from apparent ground water barrier and discontinuous surface rupture.
Dip of faulting at depth unknown, presumed to approach vertical.

SECTION B-B'

SECTION C-C'

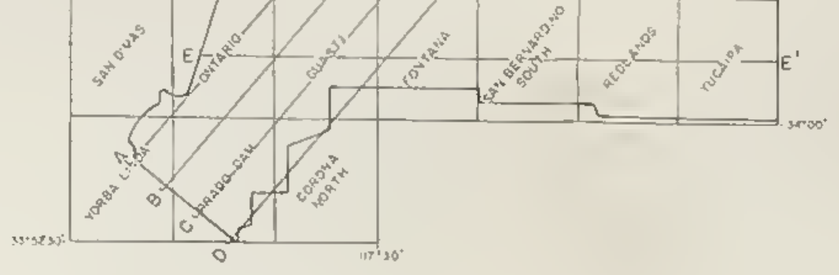
SECTION D-D'

SECTION E-E'



Location of faulting inferred from apparent ground water barrier and discontinuous surface rupture.

Dip of faulting at depth unknown, presumed to approach vertical.



GEOLOGIC SECTION INDEX

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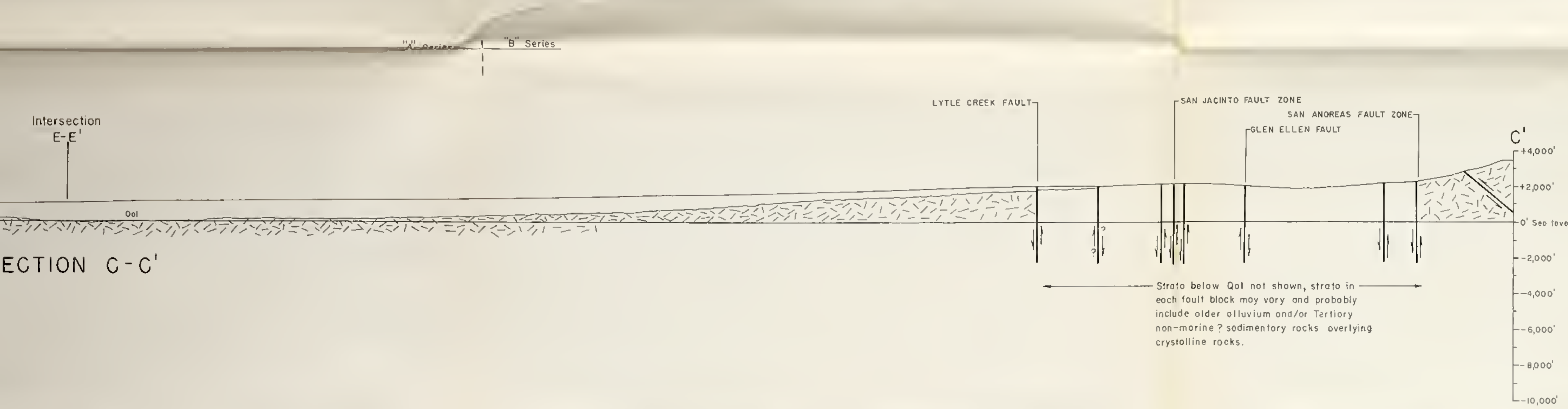


SECTION C-C'

Strata below Qal not shown, strata in each fault block may vary and probably include older alluvium and/or Tertiary non-marine ? sedimentary rocks overlying crystalline rocks.

STRATIGRAPHIC LEGEND

CENOZOIC

QUATERNARY

Qal
Alluvium and Quaternary non-marine sediments undifferentiated

TERTIARY

Miocene

Tp
Puente Formation undifferentiated, includes Sycamore Canyon, Yorba, Soquel and La Vida Members

Tt
Topanga Formation, includes volcanic rocks consisting of andesite and basaltic flows and tuffs, shown as VVVV

Tvs
Vaqueros and Sespe Formations undifferentiated.

Paleocene Eocene

Tsa
Santiago Formation

Tsi
Silverado Formation

MESOZOIC

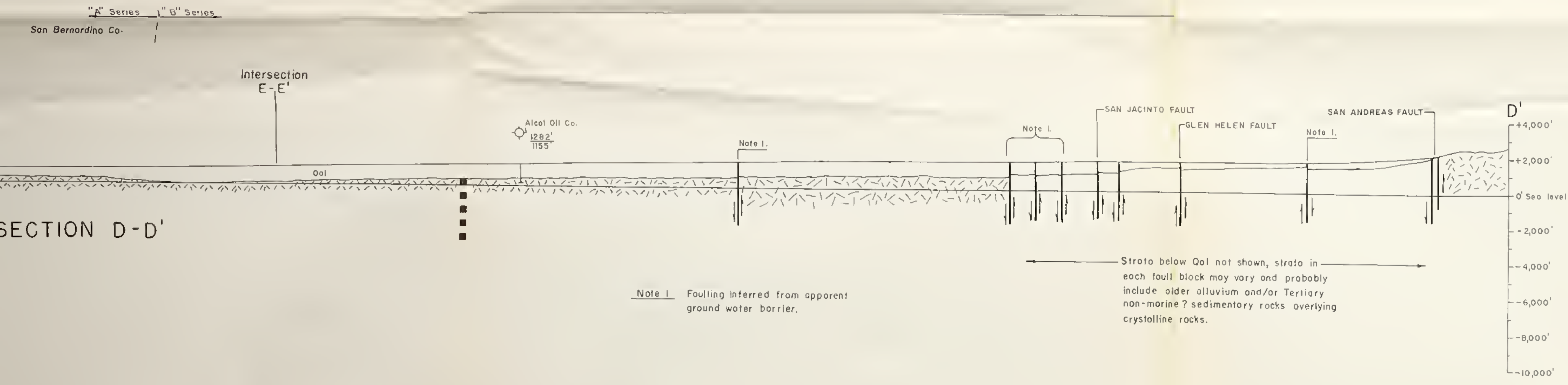
UPPER CRETACEOUS

K
Upper Cretaceous, undifferentiated. Probably includes Ladd Formation.

UPPER CRETACEOUS AND OLDER

Crystalline rock undifferentiated. Presumed to be Upper Cretaceous or older ? in age

~~ Unconformity



SECTION D-D'

Strata below Qal not shown, strata in each fault block may vary and probably include older alluvium and/or Tertiary non-marine ? sedimentary rocks overlying crystalline rocks.

Note I. Faulting inferred from apparent ground water barrier.

SYMBOLS

Shell CH4 ⌖ 609'/1068' CONTROL WELL WITH NAME OF OPERATOR AND WELL NUMBER. ELEVATION/TOTAL DEPTH

■ ■ ■ ■ ■ APPROXIMATE LOCATION OF FAULTING INFERRED FROM SEISMIC ACTIVITY

SCHEMATIC REPRESENTATION OF FAULT SCARP ROCK TALUS AND DETRITUS.

FAULT SHOWING RELATIVE MOVEMENT

SECTION E-E'

Strata below Qal not shown, strata in each fault block may vary and probably include older alluvium and/or Tertiary nonmarine (San Timoteo Formation) sedimentary rocks overlying crystalline rocks.

DRAFTED BY B. LINDGREN

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SPECIAL REPORT 113
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EARTHQUAKE EPICENTERS IN SOUTHERN CALIFORNIA
1910-1971

MAGNITUDE 4 AND GREATER

By DONALD A. RODGERS 1974

Earthquakes with magnitude 4.0 and greater
in southwestern San Bernardino County
1910 - 1971

SYMBOLS USED

◇	MAGNITUDE 4.0 - 4.9
○	MAGNITUDE 5.0 - 5.9
□	MAGNITUDE 6.0 - 6.9
✳	MAGNITUDE 7.0 - 7.9

NOTE: Historic and Quaternary faults taken from "Preliminary Fault Map of California" published by California Division of Mines and Geology

SCALE 1:750,000

(1 inch equals approximately 12 miles)

10 0 10 20 30 40 Miles

10 0 10 20 30 40 50 Kilometers

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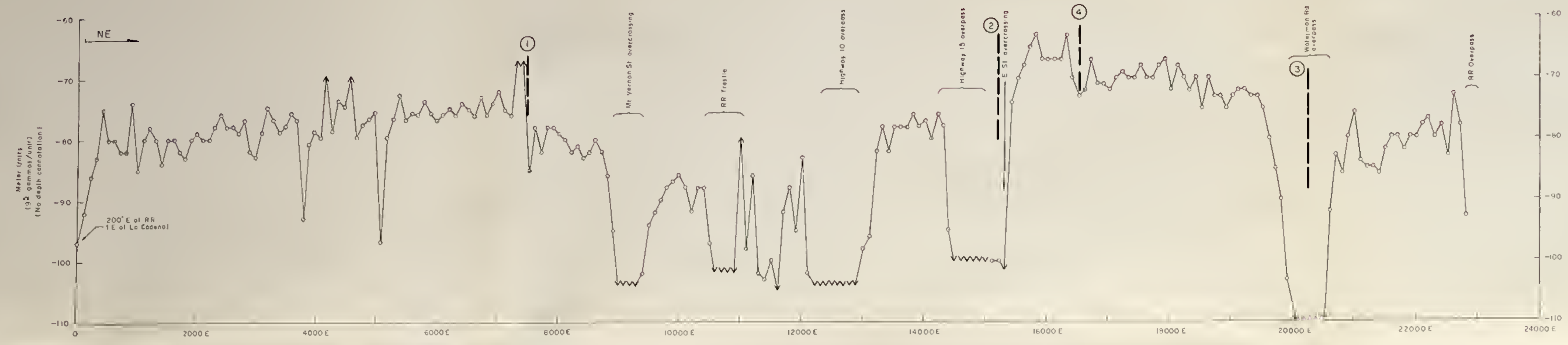
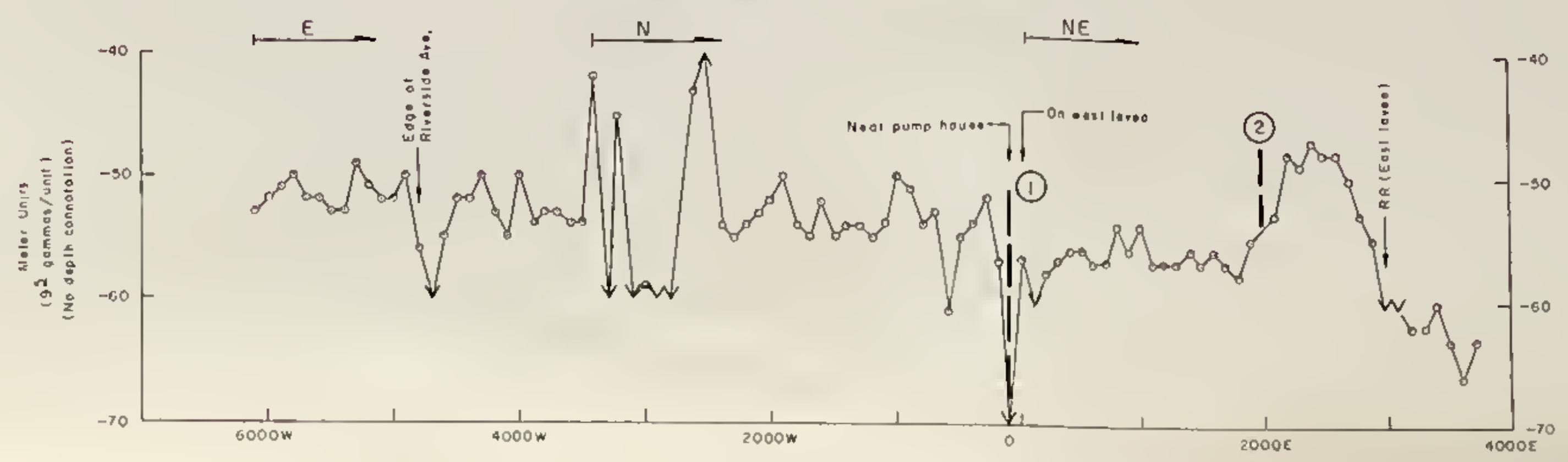
MAGNETOMETER TRAVERSES

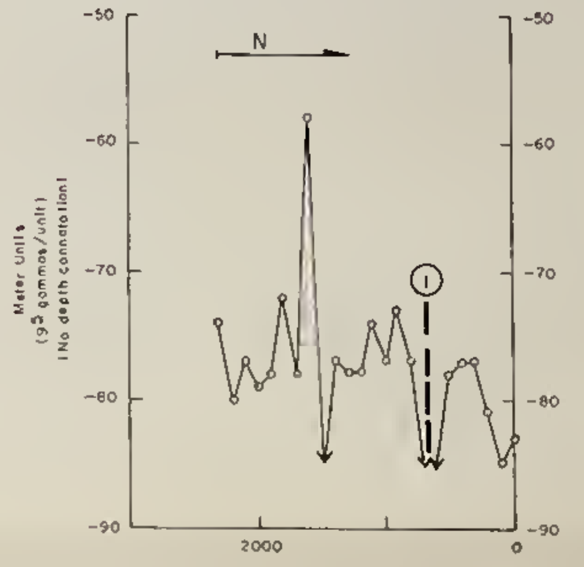
MAGNETOMETER TRAVERSE M 1



MAGNETOMETER TRAVERSE M3



MAGNETOMETER TRAVERSE M 5
(MT. VERNON AVE.)



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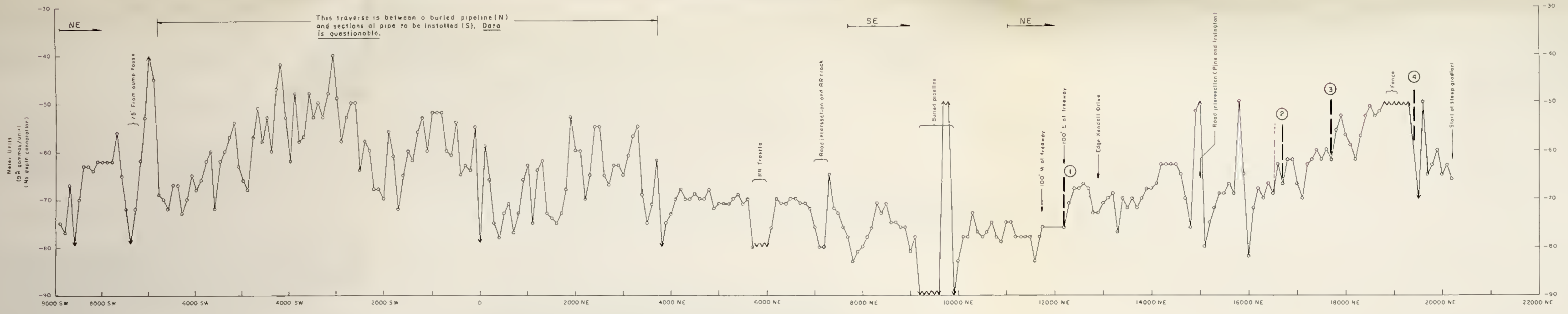
MAGNETOMETER TRAVERSE M 2



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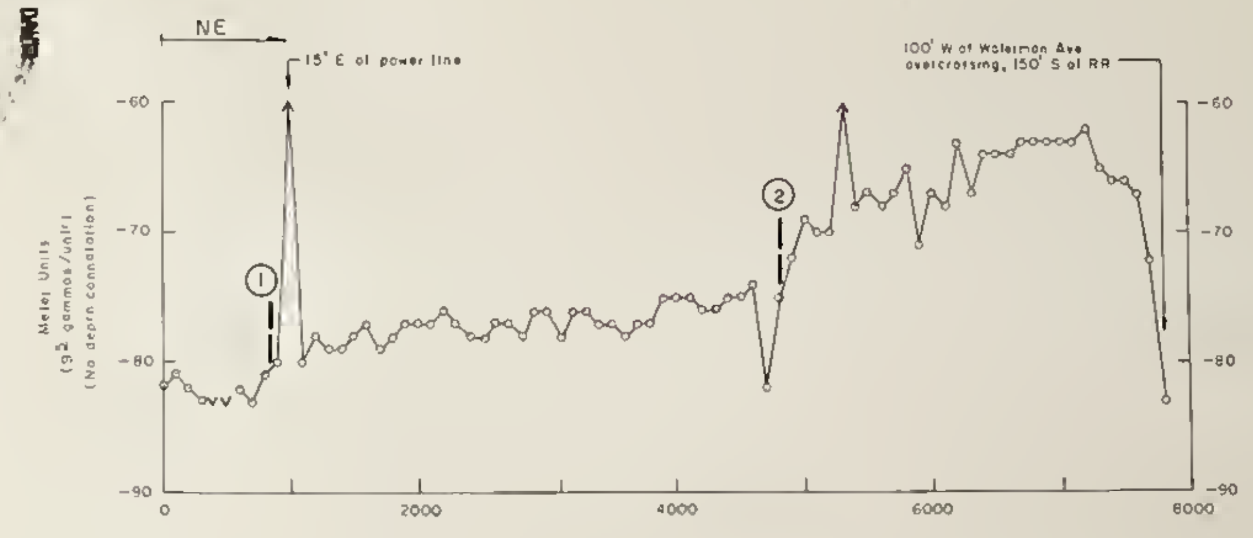
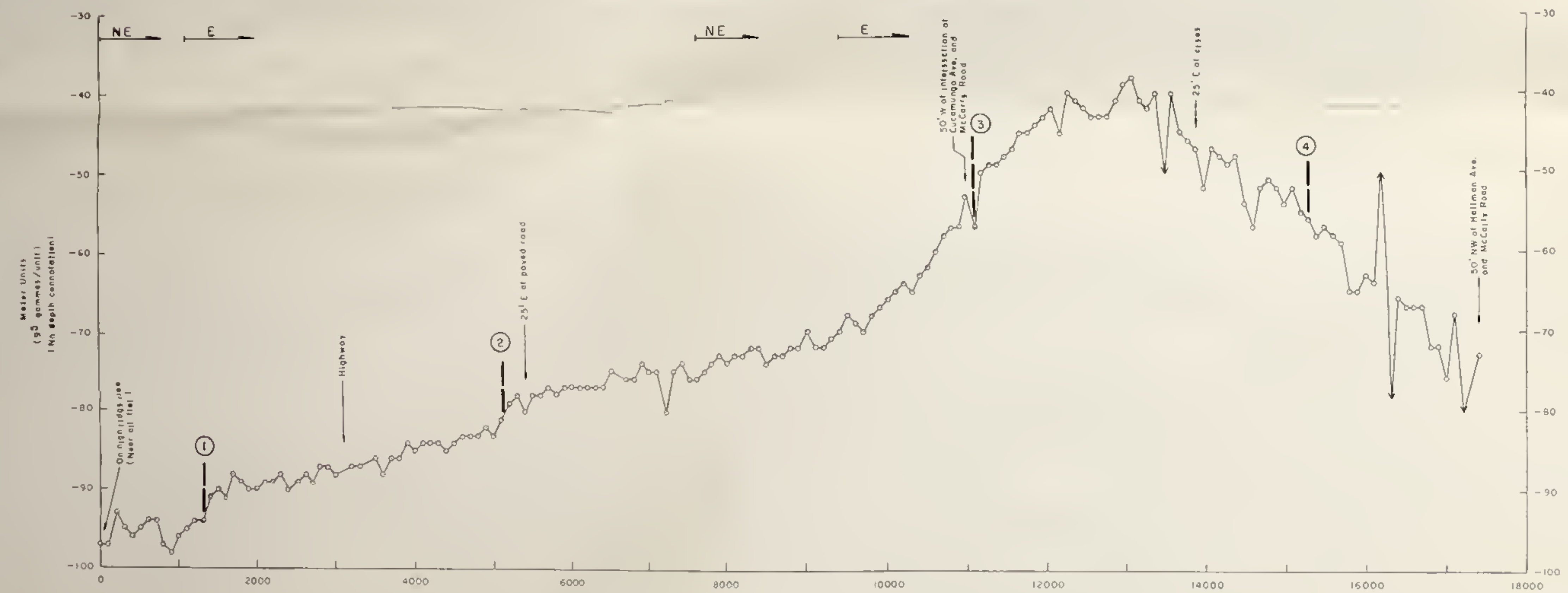
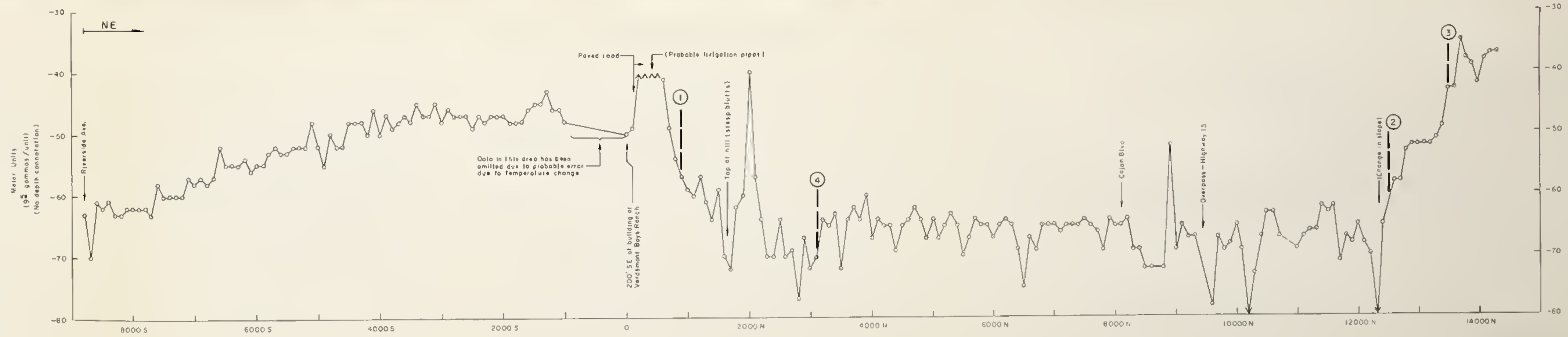
MAGNETOMETER TRAVERSE M 4 (WASHINGTON ST. TO WATERMAN ROAD – NE)



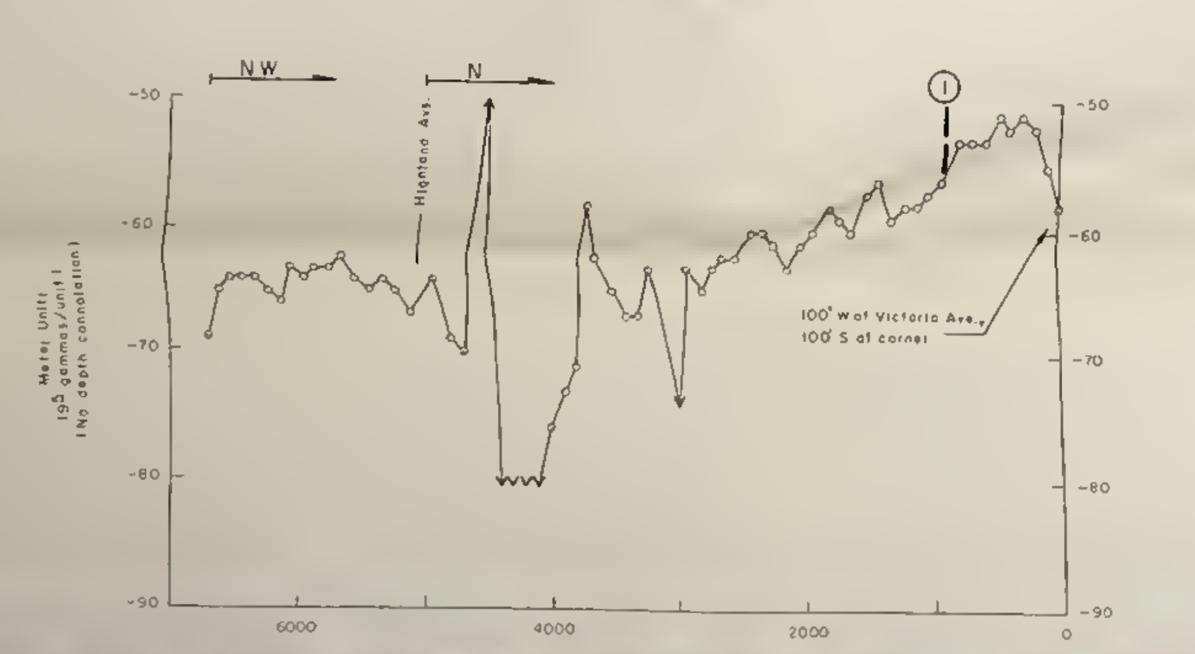
MAGNETOMETER TRAVERSE M 8 (CHINO FAULT)



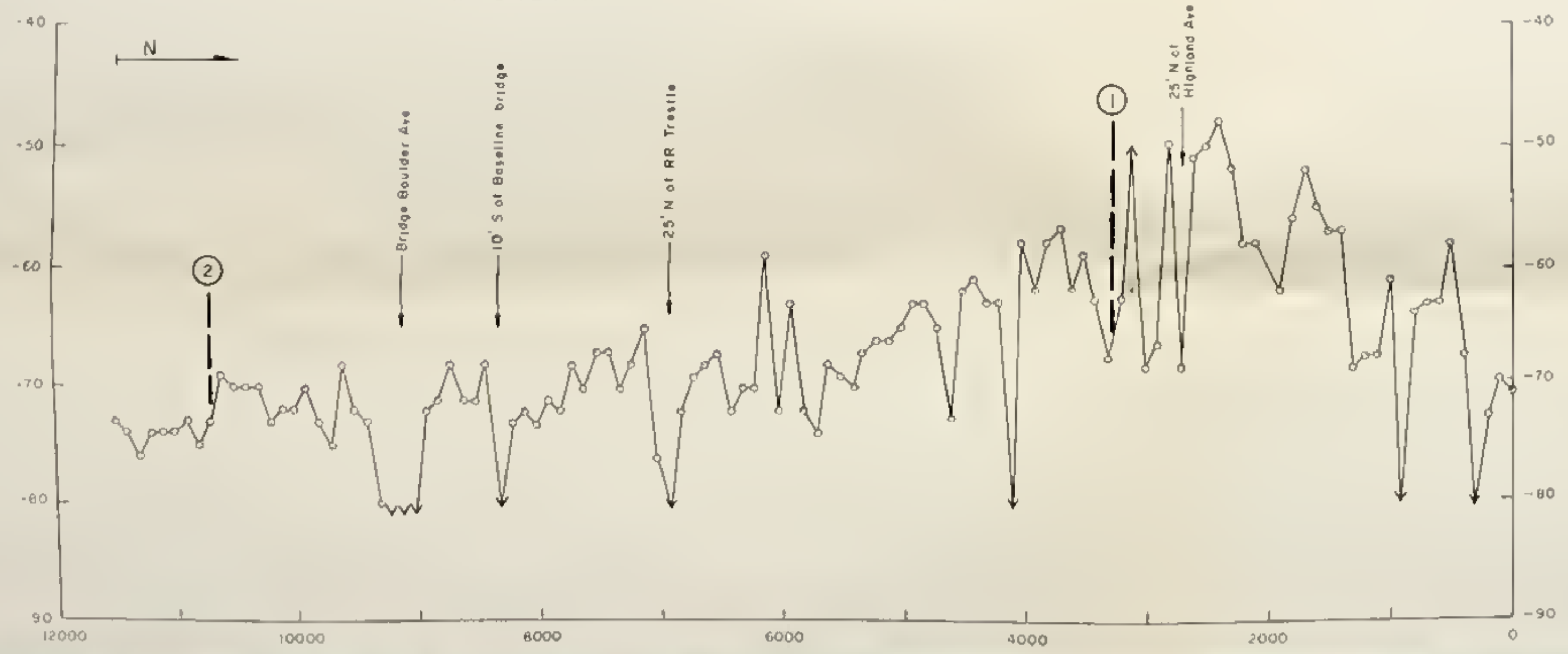
MAGNETOMETER TRAVERSE M 6 (VEROMONT RANCH AREA)



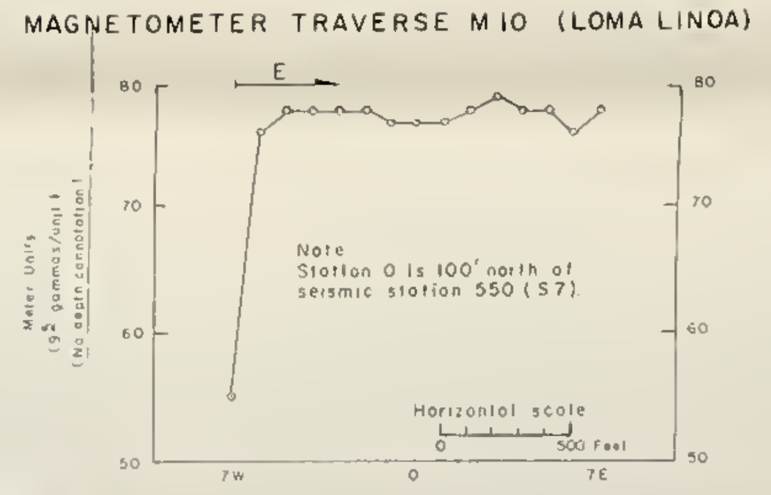
MAGNETOMETER TRAVERSE M 7
(VICTORIA AVE. – PATTON STATE HOSPITAL)



MAGNETOMETER TRAVERSE M 9 (CITY CREEK)



MAGNETOMETER TRAVERSE M 10 (LOMA LINDA)



EXPLANATION FOR MAGNETOMETER TRAVERSES

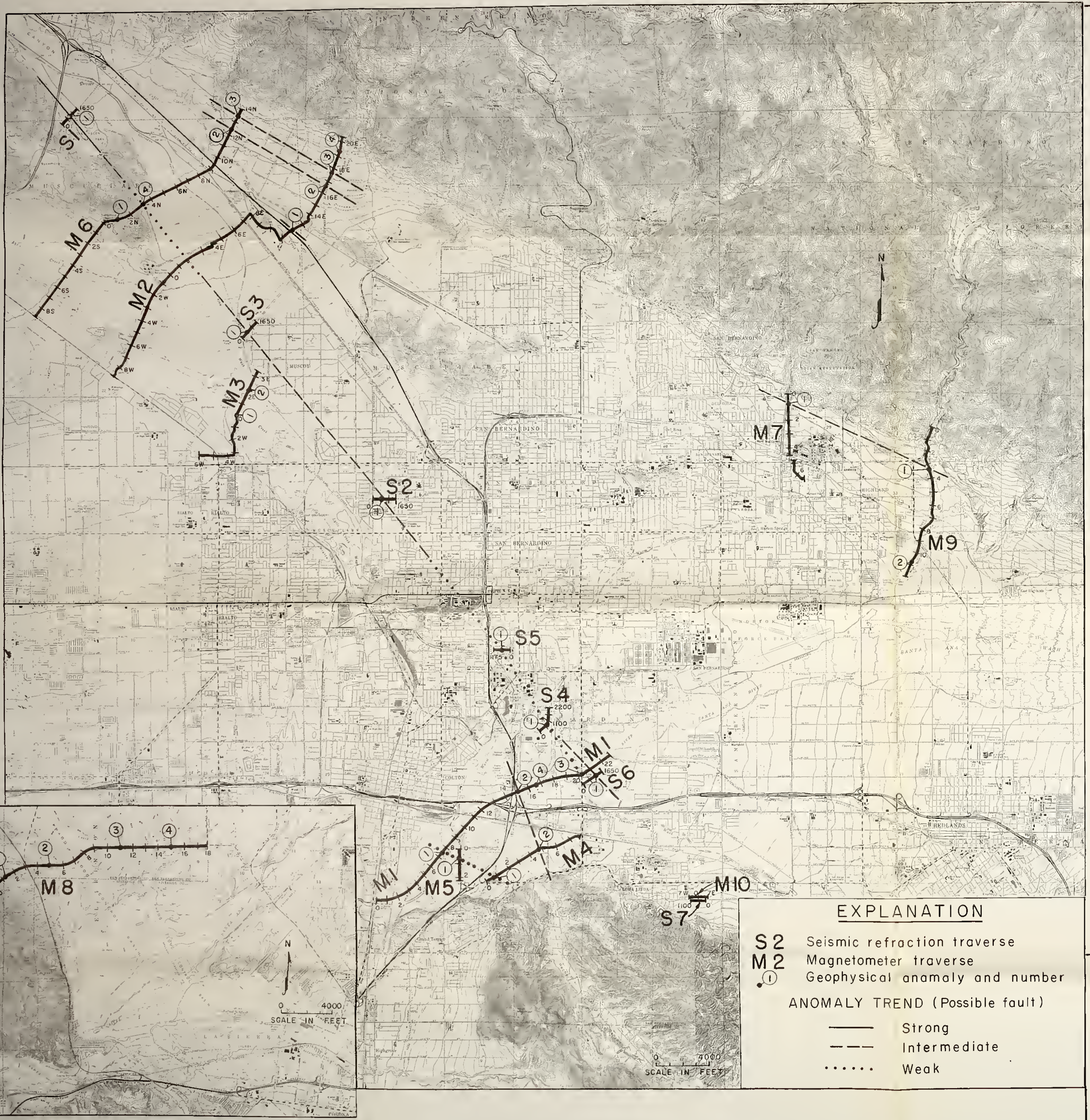
° Magnetometer reading

X Data greater than plotted points

Vertical magnetic intensity levels (100' Stations)

⑤ Magnetic anomaly and number

Horizontal scale
0 1000 Feet
0 200 400 Meters



EXPLANATION

S2	Seismic refraction traverse
M2	Magnetometer traverse
①	Geophysical anamaly and number

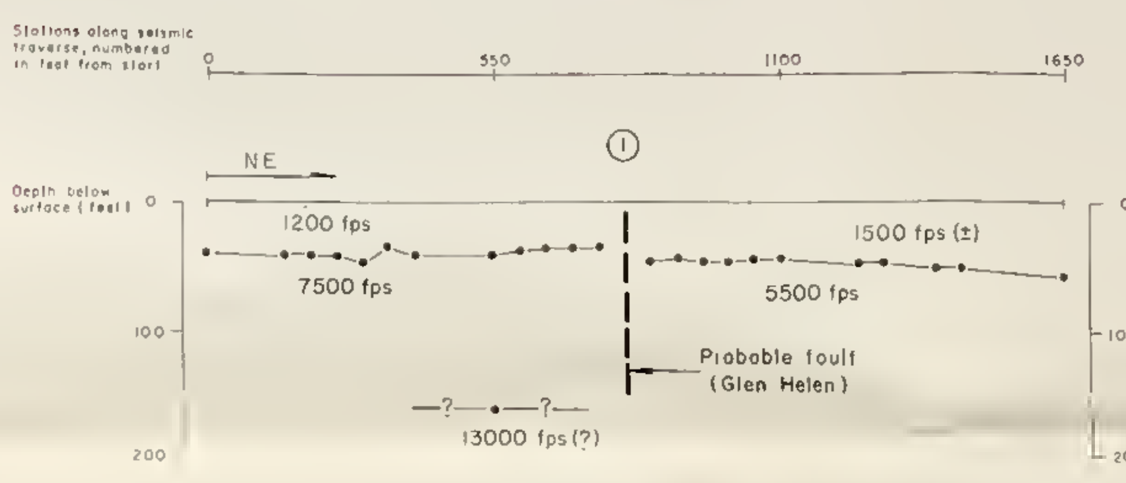
ANOMALY TREND (Possible fault)

———	Strong
— — —	Intermediate
......	Weak

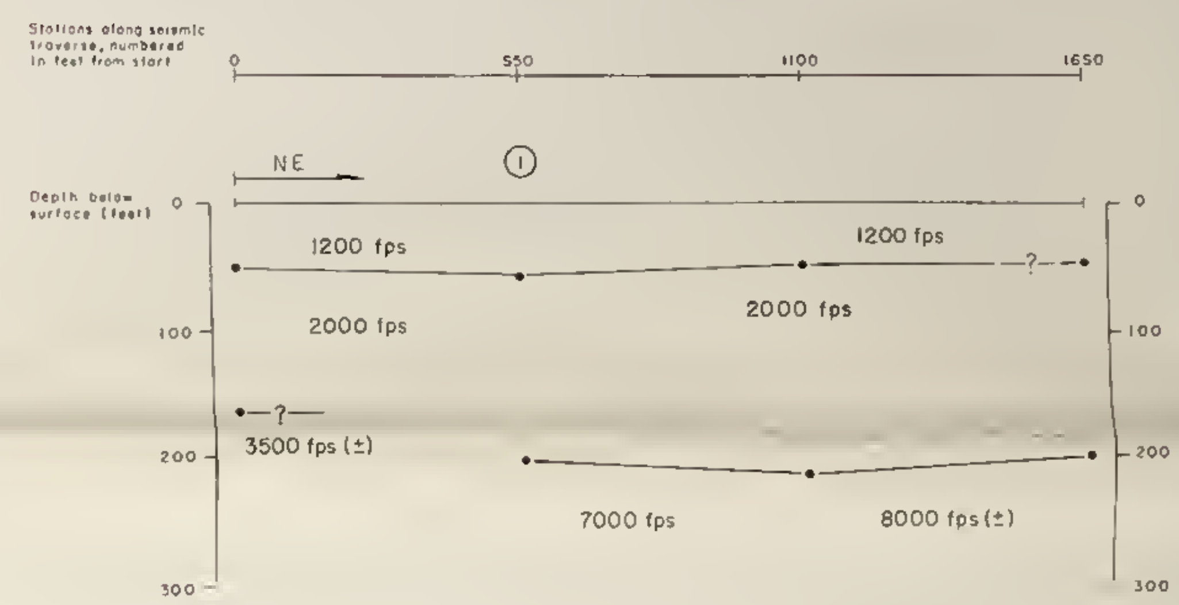
Index map showing generalized locations of seismic and magnetometer traverses. Insert shows traverse M8 across Prado Flood Control Basin north of Corona.

SEISMIC TRAVERSES

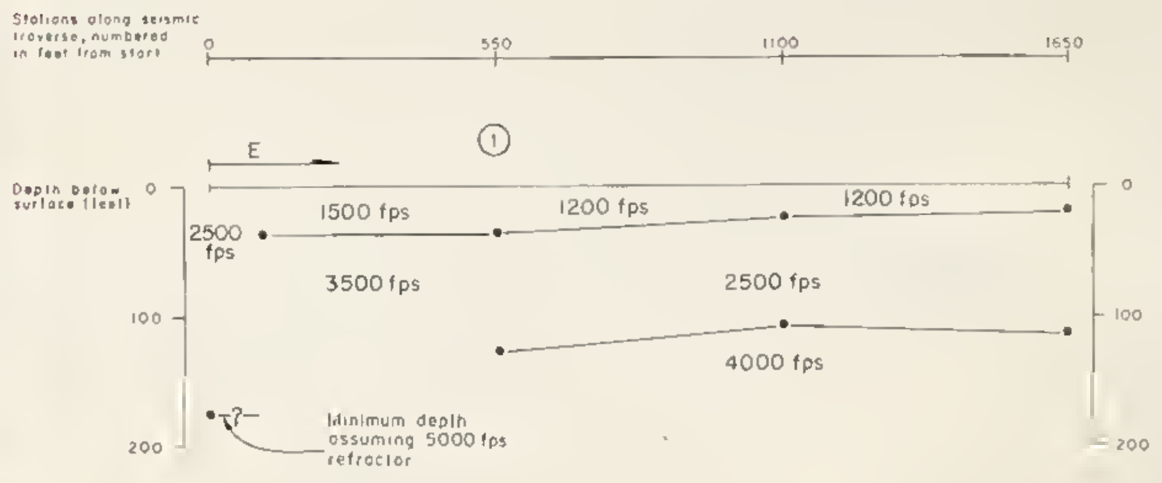
CROSS SECTION ALONG SEISMIC TRAVERSE S1 (GLEN HELEN PARK)


Stations along seismic traverse, numbered in feet from start
0
550
1100
1650
NE
①
Depth below surface (feet)
0
100
200
1200 fps
1500 fps (±)
7500 fps
5500 fps
Probable fault (Glen Helen)
13000 fps (?)

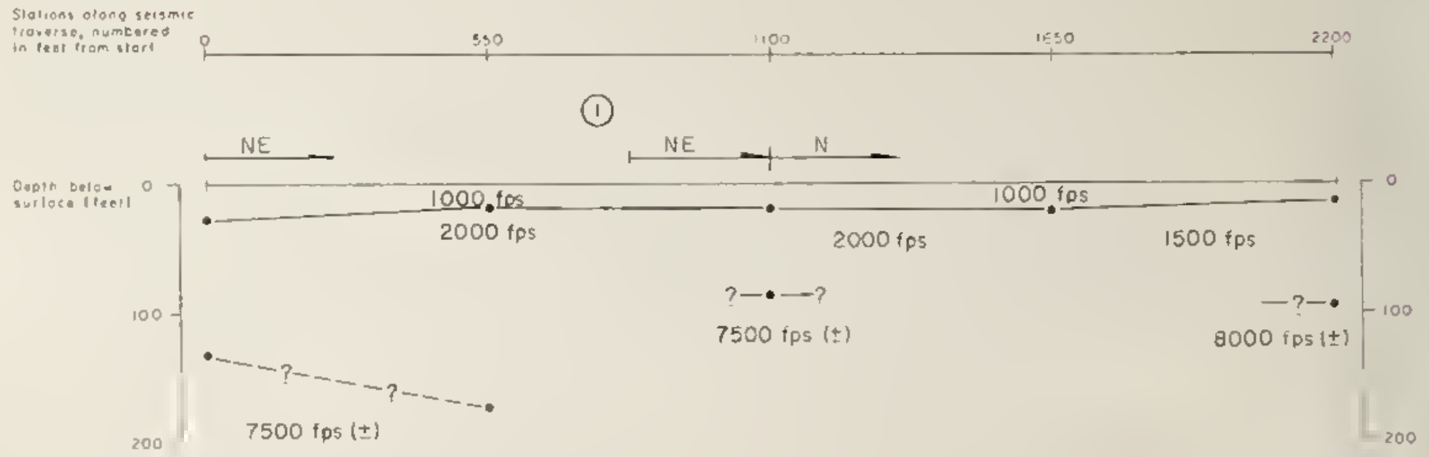
CROSS SECTION ALONG SEISMIC TRAVERSE S2 (16TH ST. - MUSCOY)



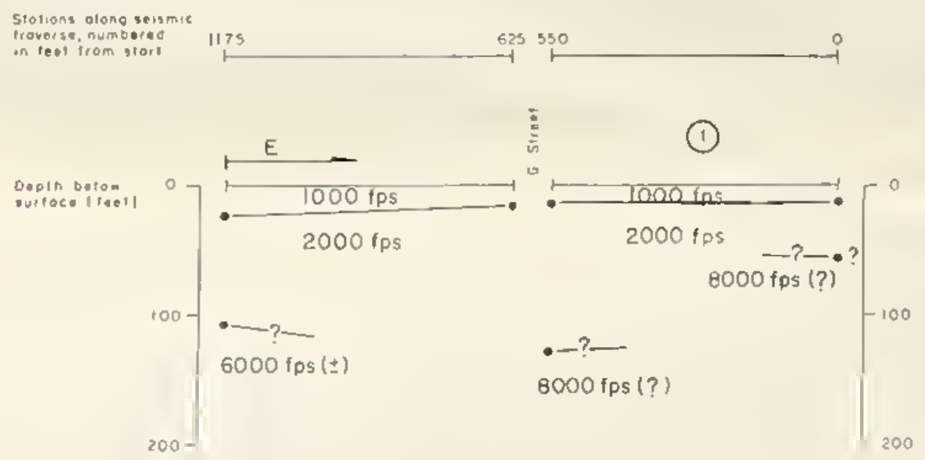
CROSS SECTION ALONG SEISMIC TRAVERSE S3 (LEVEE BANK - MUSCOY)


Stations along seismic traverse, numbered in feet from start
0
550
1100
1650
E
①
Depth below surface (feet)
0
100
200
2500 fps
1500 fps
1200 fps
1200 fps
3500 fps
2500 fps
4000 fps
Minimum depth assuming 5000 fps refractor

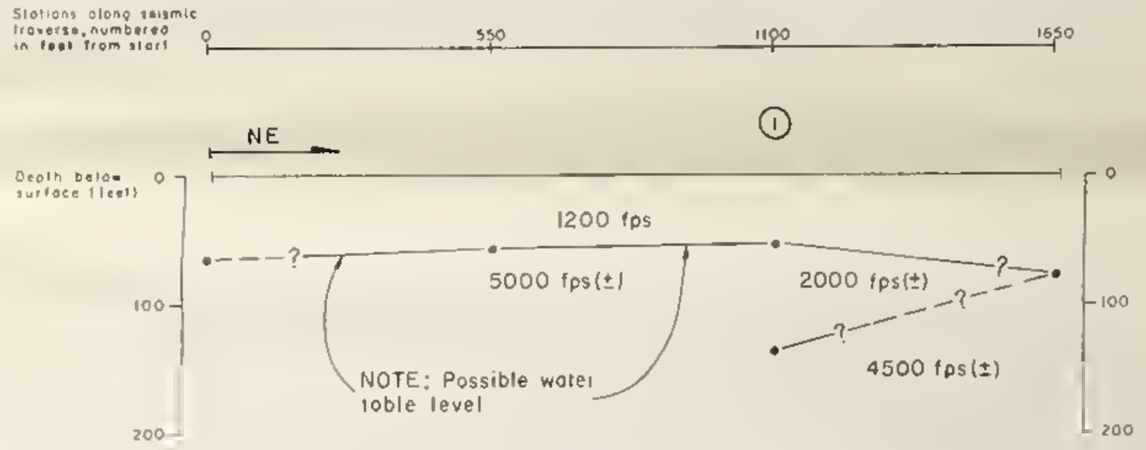
CROSS SECTION ALONG SEISMIC TRAVERSE S4 (SAN BERNARDINO)



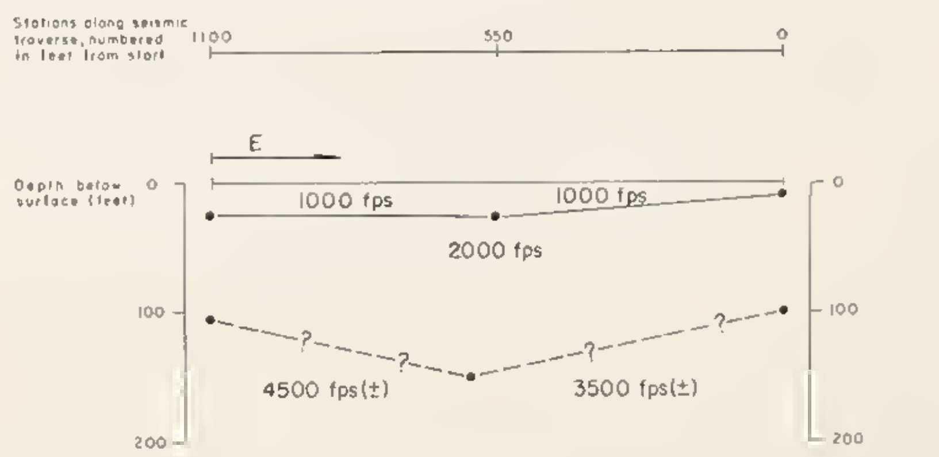
CROSS SECTION ALONG SEISMIC TRAVERSE S5 (SAN BERNARDINO)



CROSS SECTION ALONG SEISMIC TRAVERSE S6 (AIRPORT)


Stations along seismic traverse, numbered in feet from start
0
550
1100
1650
NE
①
Depth below surface (feet)
0
100
200
1200 fps
5000 fps (±)
2000 fps (±)
4500 fps (±)
NOTE: Possible water table level

CROSS SECTION ALONG SEISMIC TRAVERSE S7 (LOMA LINDA)


Stations along seismic traverse, numbered in feet from start
1100
550
0
E
Depth below surface (feet)
0
100
200
1000 fps
1000 fps
2000 fps
4500 fps (±)
3500 fps (±)

EXPLANATION FOR SEISMIC TRAVERSES

— — —	Probable fault
•	Depth point
fps	Feet per second
•⁄•—•	Seismic horizon (Dashed — poor data, questioned — very poor data)
①	Anomalous area below numbered circle

Horizontal scale

0 250 Feet

0 50 100 Meters

SEISMIC AND MAGNETOMETER TRAVERSES
SOUTHWESTERN SAN BERNARDINO COUNTY, CALIFORNIA

CROSS SECTIONS CONSTRUCTED BY
INTERPRETATION OF SEISMIC DATA

BY RODGER CHAPMAN AND GORDON W. CHASE

1974

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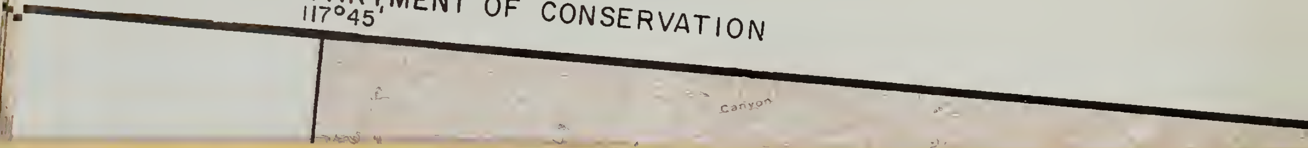
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION



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